GFDL Seasonal to Decadal Predictions: Challenges and Issues

1. GFDL Seasonal to Decadal Predictions with CM2.1

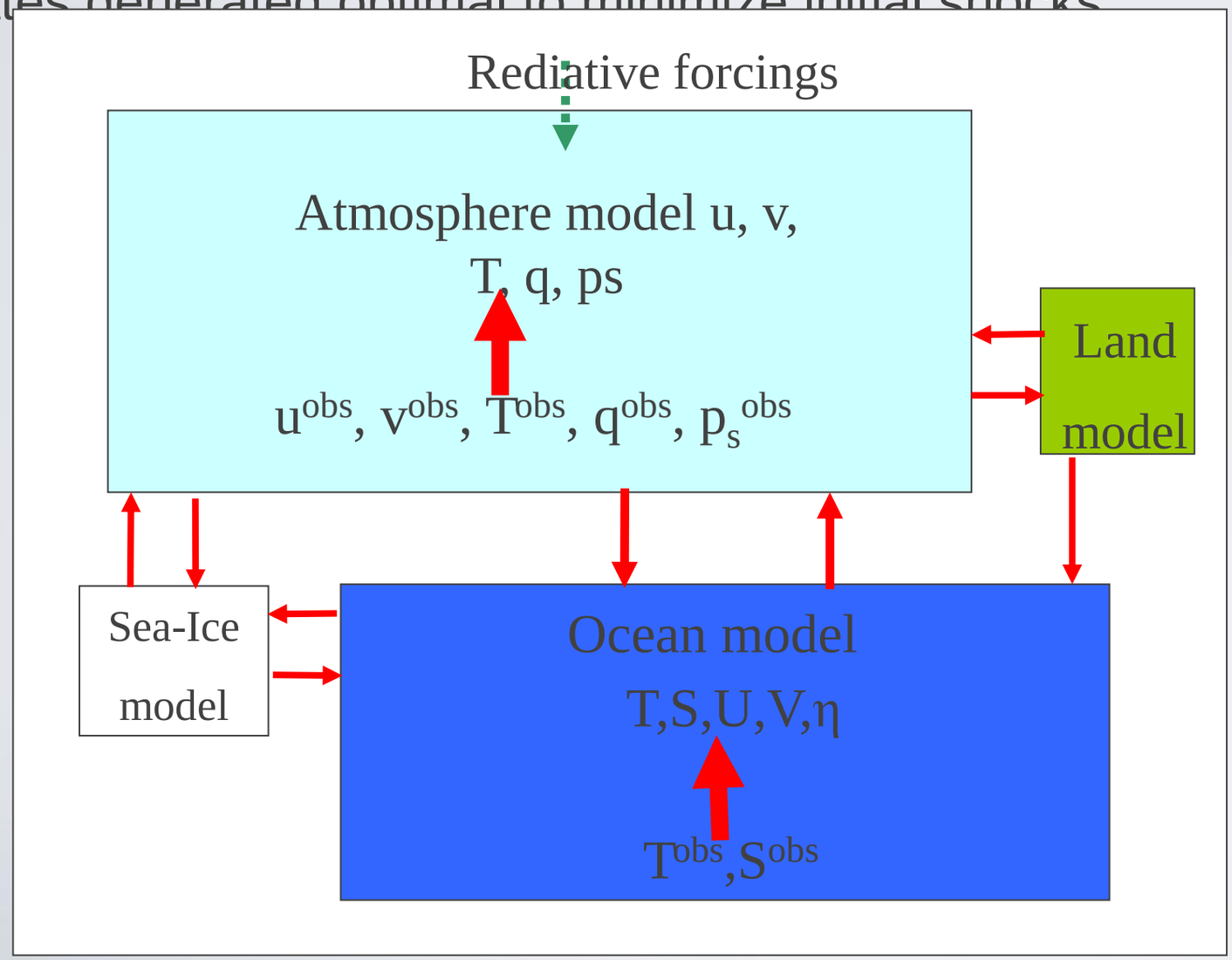
2. New GFDL model for prediction across scales: CM2.5-FLOR

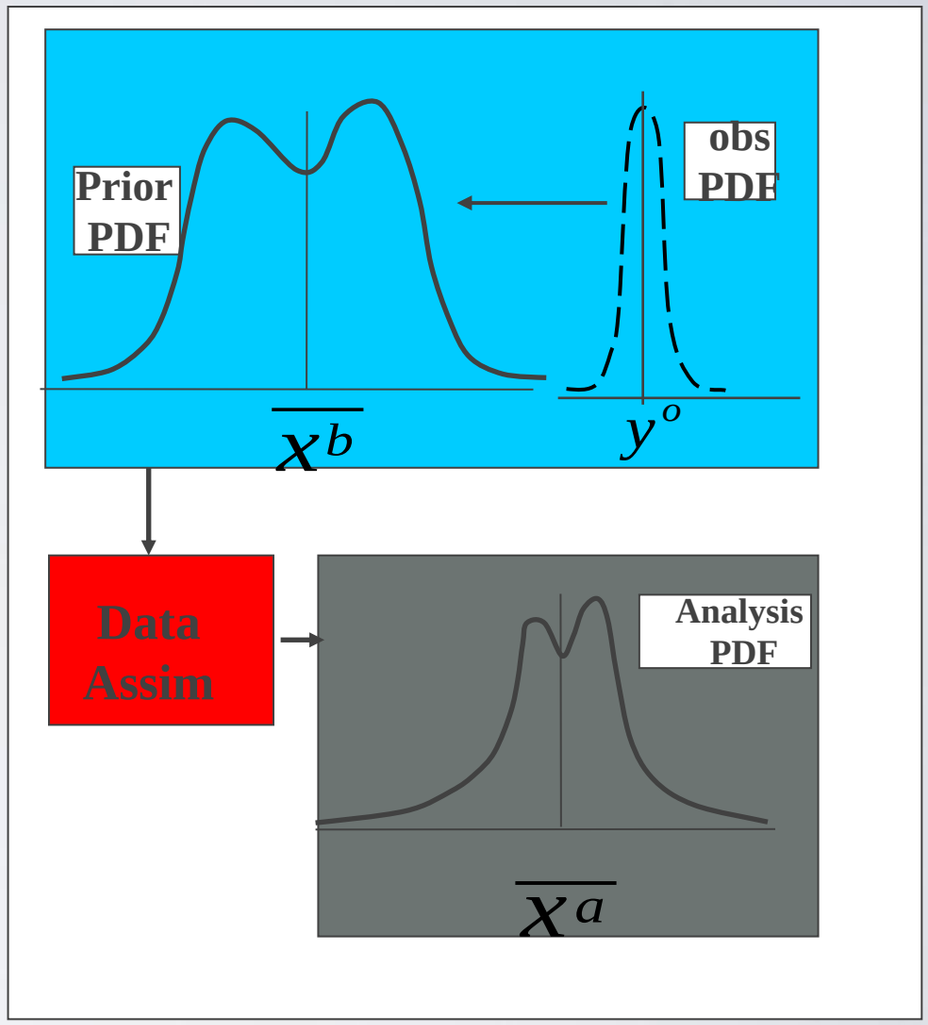
Ensemble Coupled Data Assimilation (ECDA)

An ensemble of model integrations establishes the background error statistics to extract the observational information, addressing the probabilistic nature of climate evolution.

- ✓ Ensemble statistics provide multivariate relationships, *e.g.,* T-S relationship and geostrophic balance

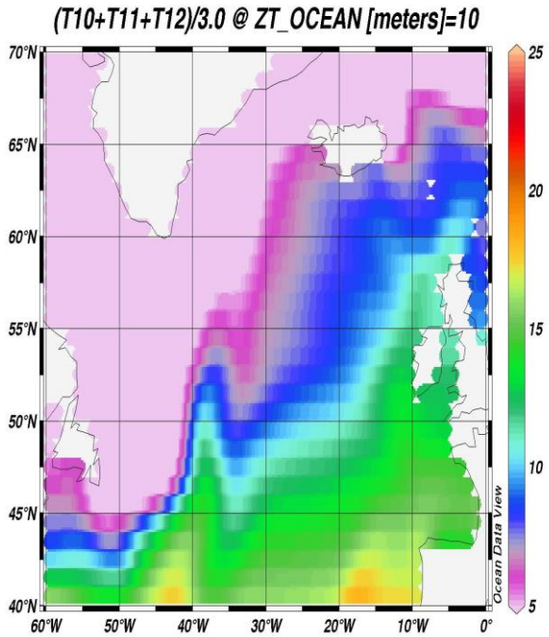
- ✓ A set of self-balanced and coherent initial coupled states generated optimal to minimize initial shocks



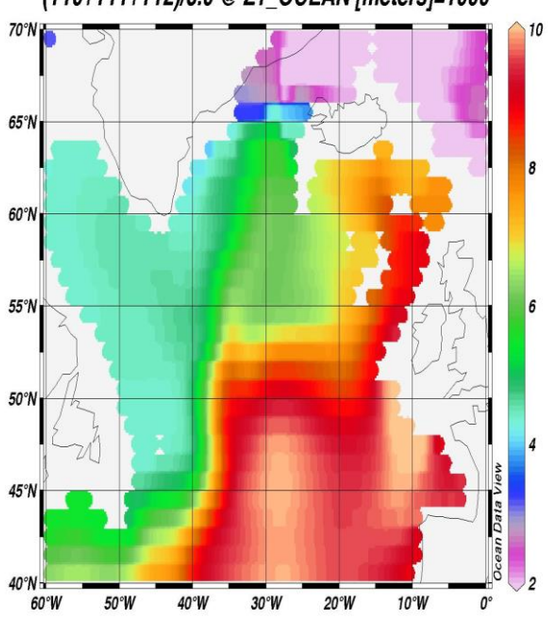


October-December North Atlantic Temperature

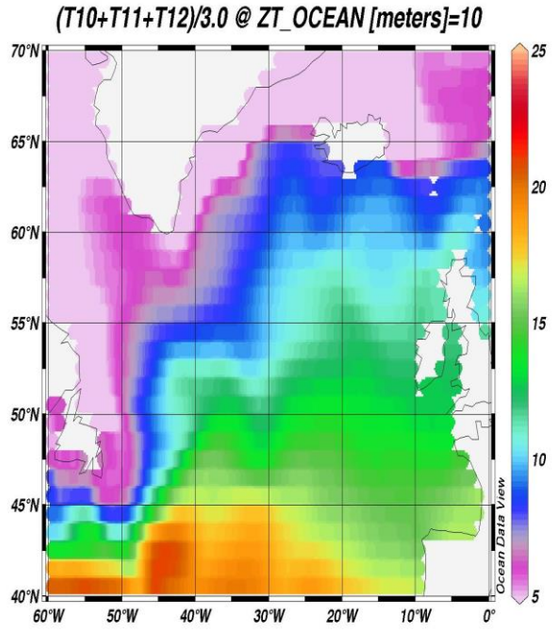
NO-ASSIM



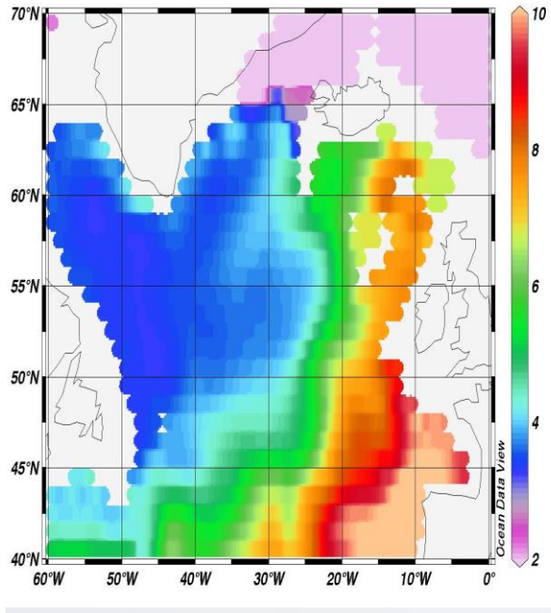
CM2_OND_2004



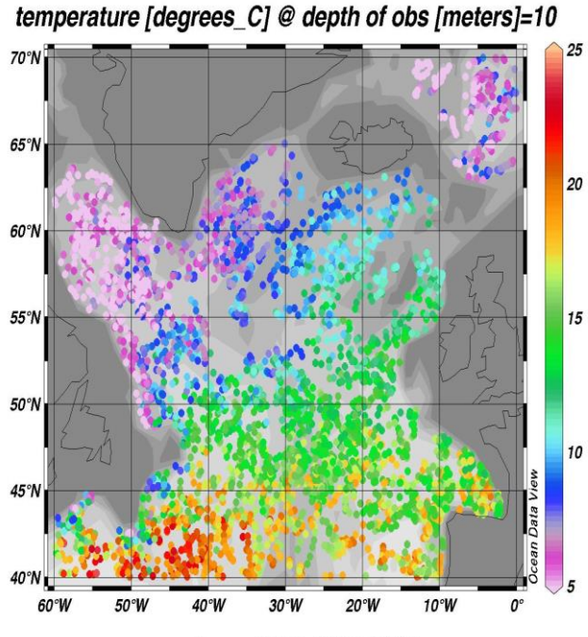
ASSIM(ECDA)



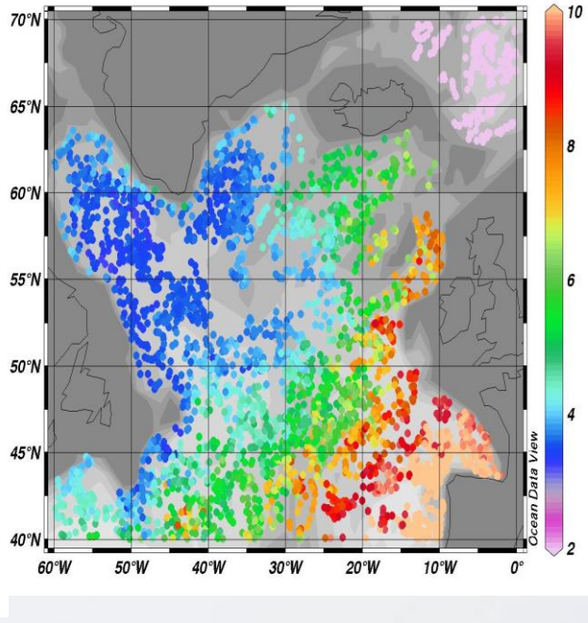
EAKF_OND_2004



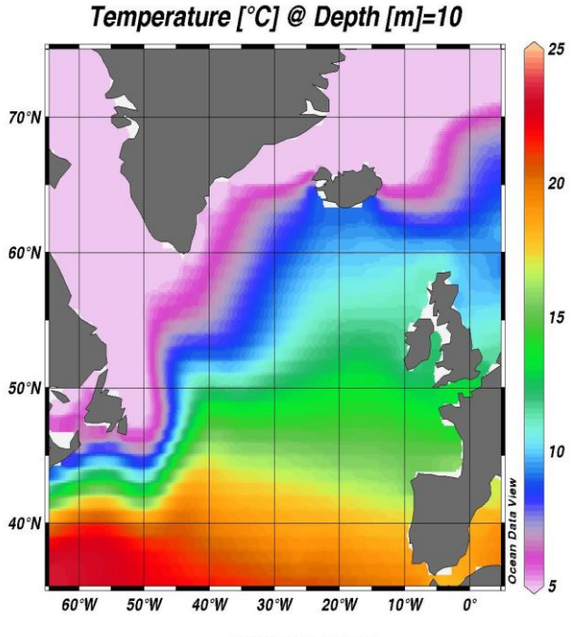
Argo



Argo_OND_2002-2006



WOA01



WOA01_OND

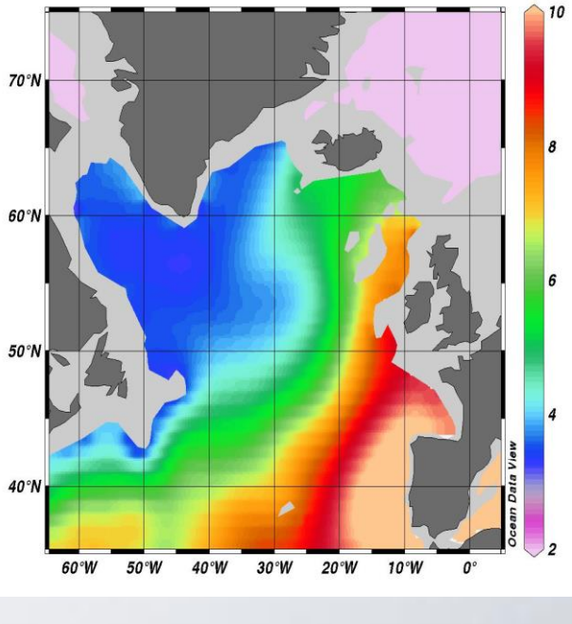


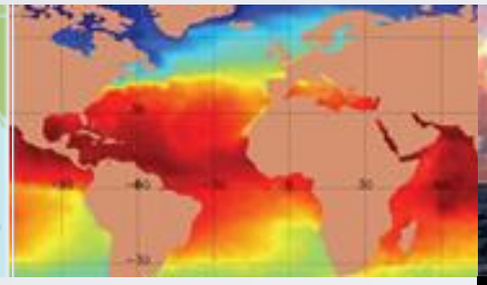
Figure: You-Soon Chang

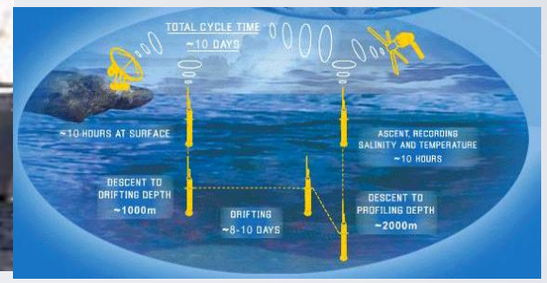
Ocean observations assimilated

1982 — XBT's 60's

1993 — Satellite SST

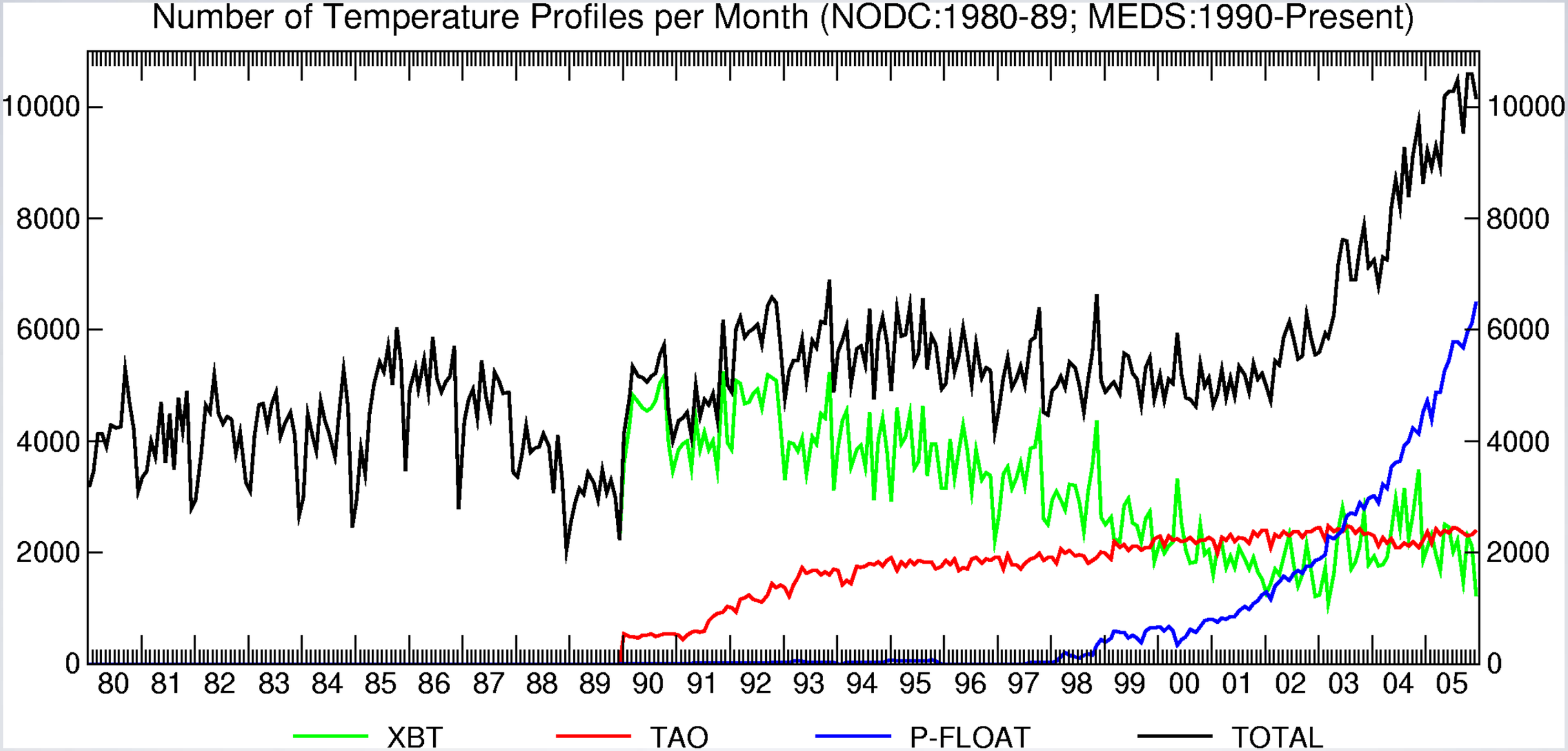
2001 — Moorings/Altimeter ARGO



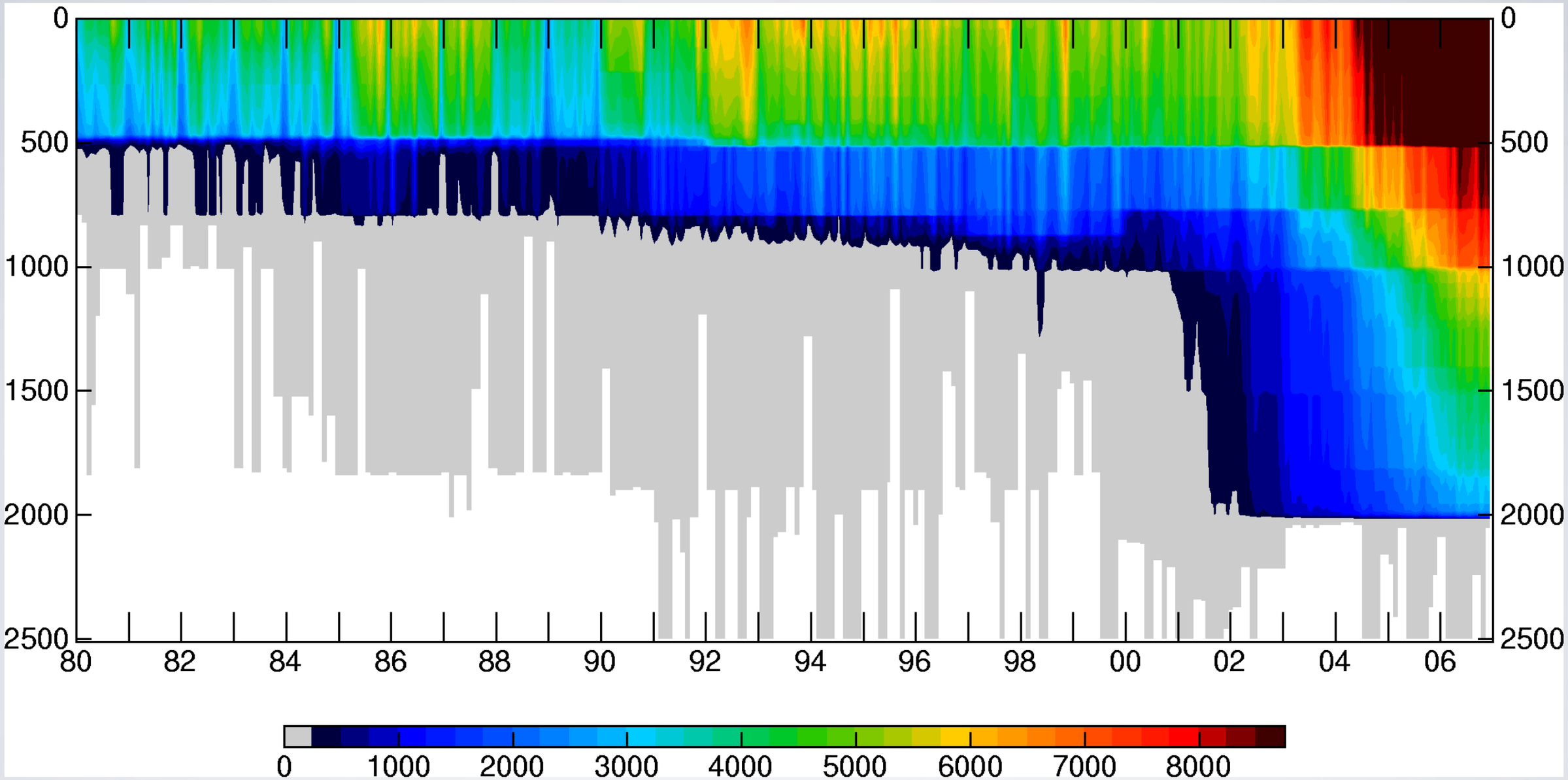


The ocean observing system has slowly been building up…

Its non-stationary nature is a challenge for the estimation of decadal variability and for interpreting initialized predictions


Number of Temperature Profiles per Month (NODC:1980-89; MEDS:1990-Present)
10000
8000
6000
4000
2000
0
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05
XBT
TAO
P-FLOAT
TOTAL

Number of Temperature Observations per Month as a Function of Depth

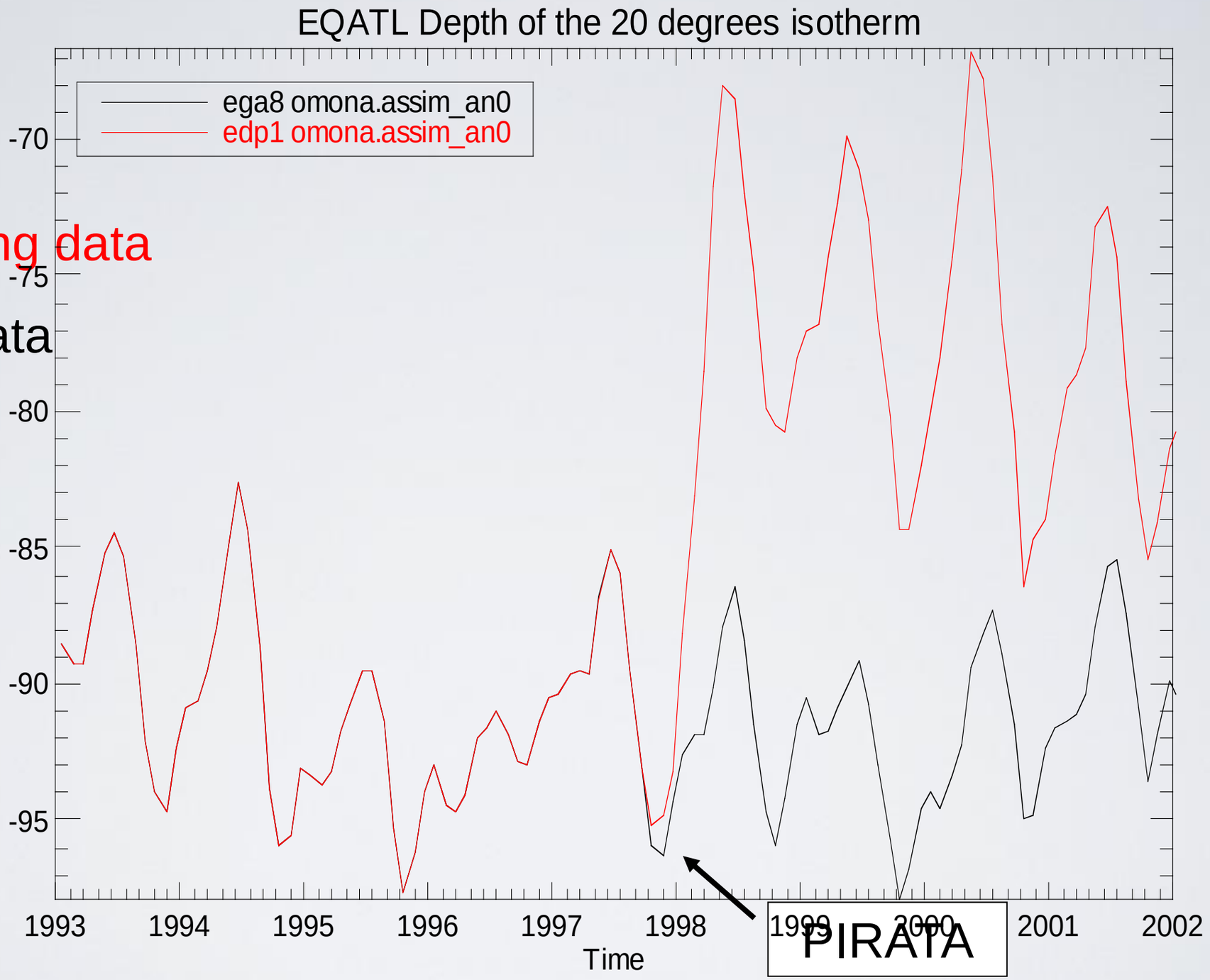


D. Behringer

Example of potential problem:

Assim of mooring data

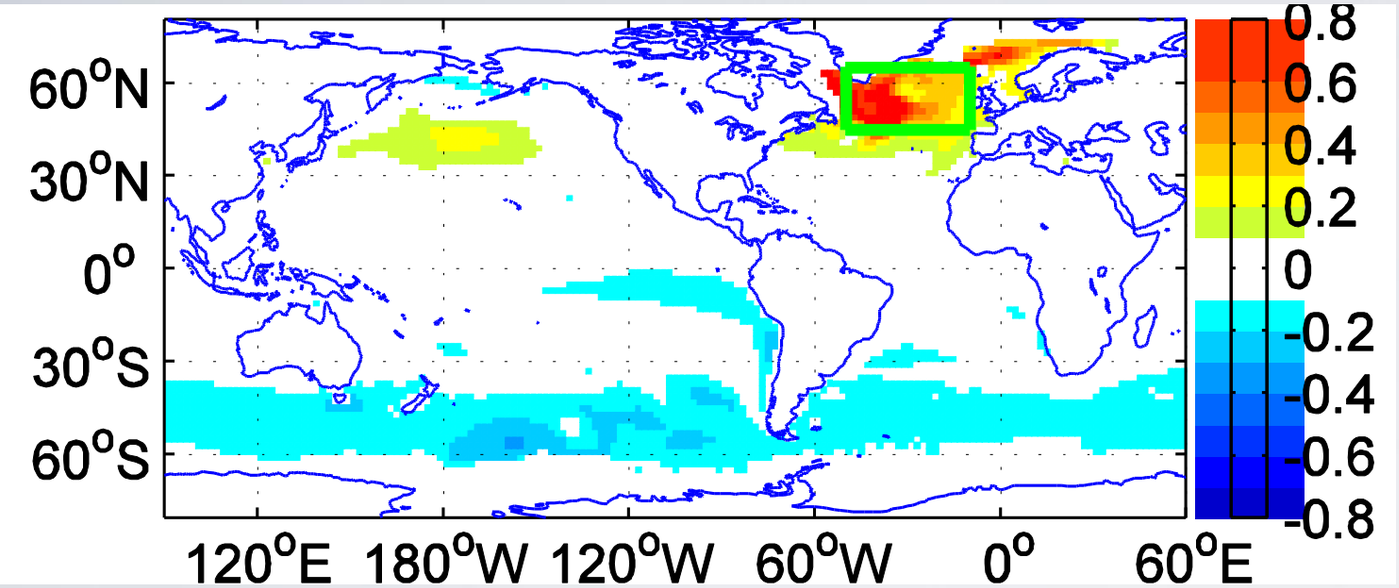
CTL=No data

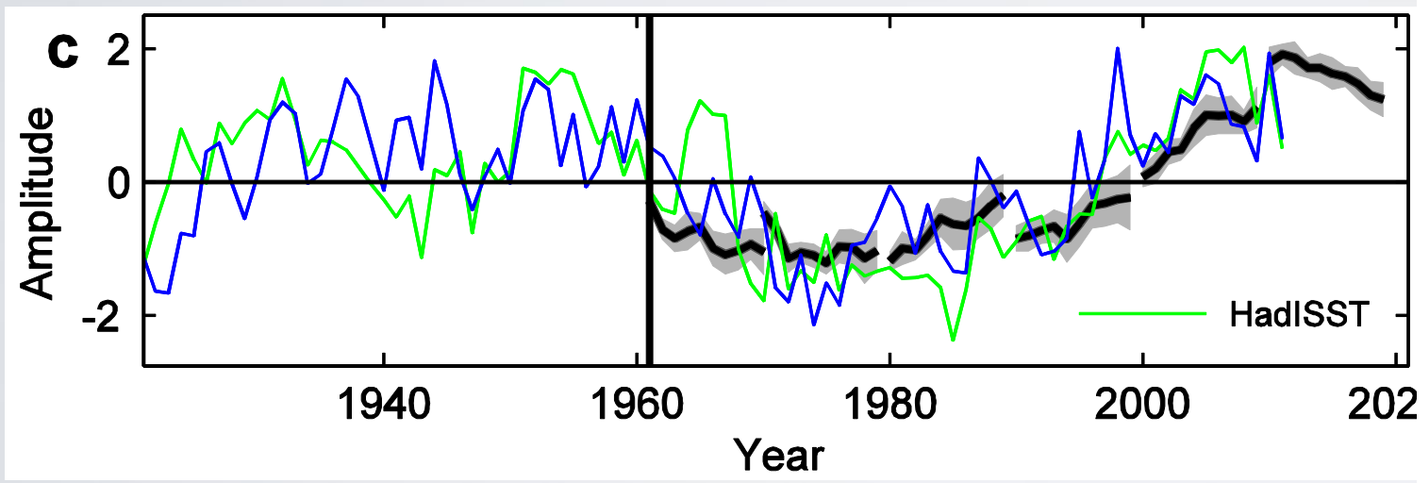


Large impact of data in the mean state: Shallower thermocline

A predictable AMO-like pattern in GFDL's decadal hindcasts

Most Predictable SST Pattern



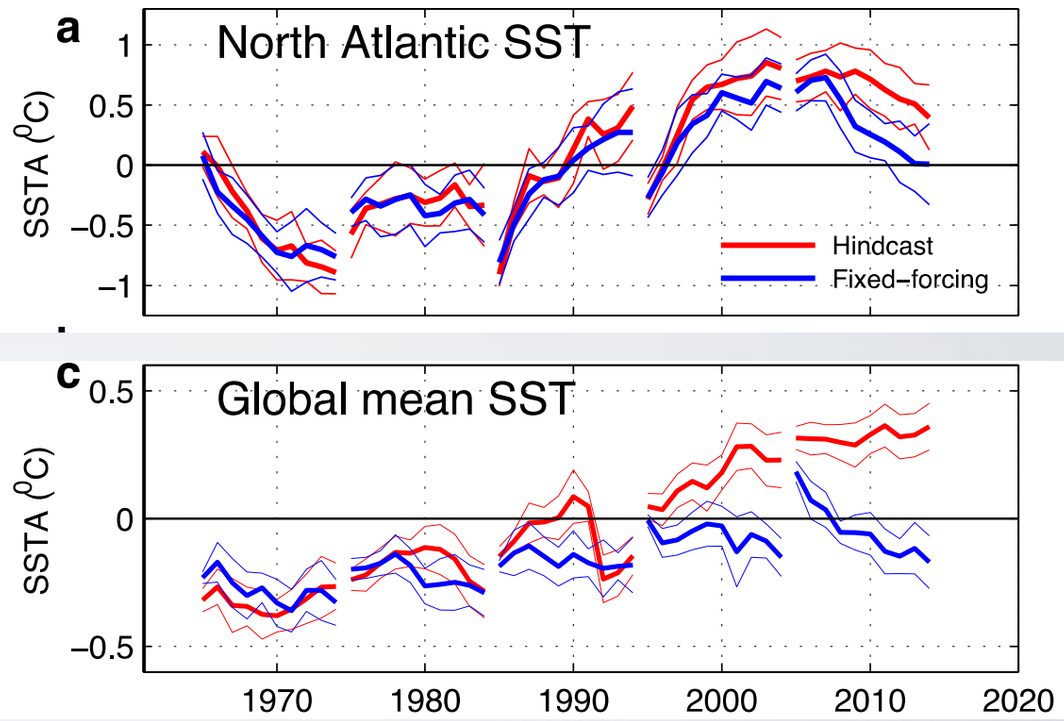


Yang et al. (2013, J. Climate)

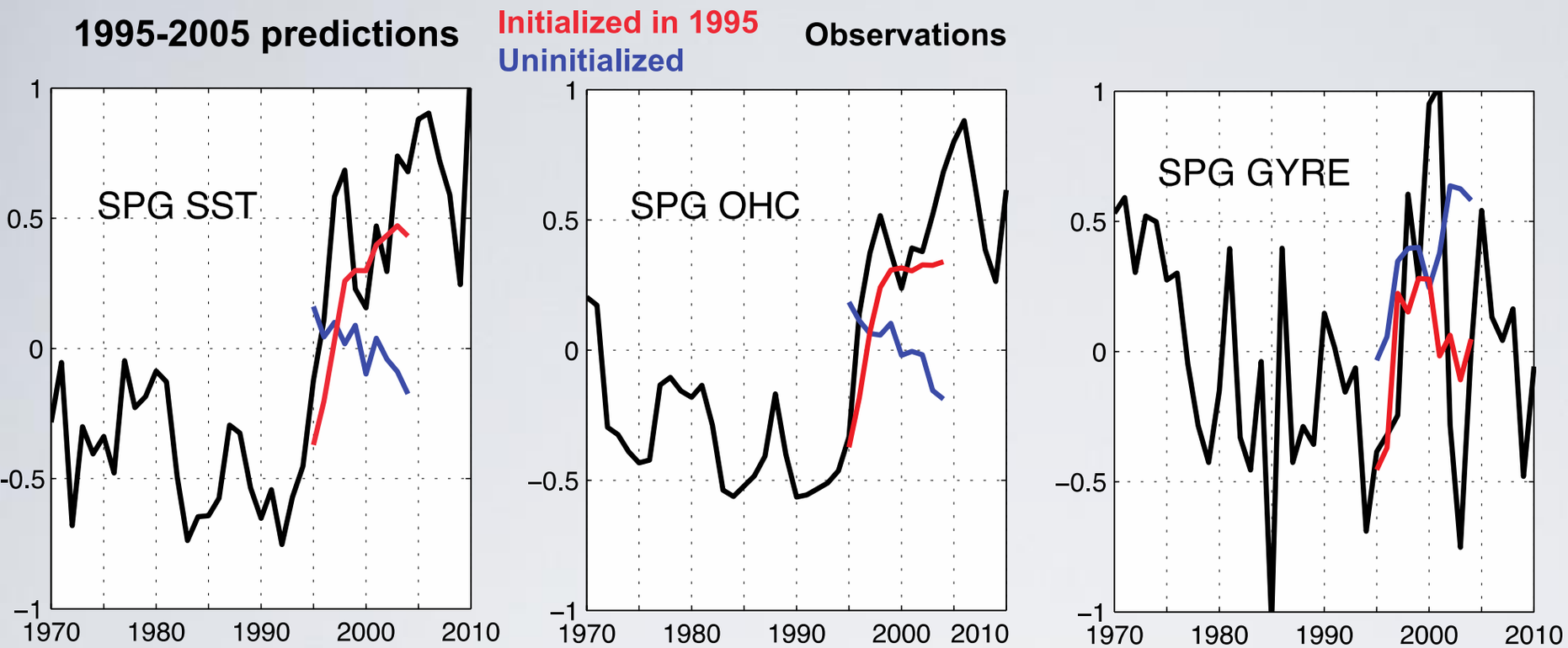
Inter-hemisphere dipole; strong in North Atlantic

Time series well correlated with the AMO index & Hindcasts follow observations

N. Atl. Predictability due to Internal Variability

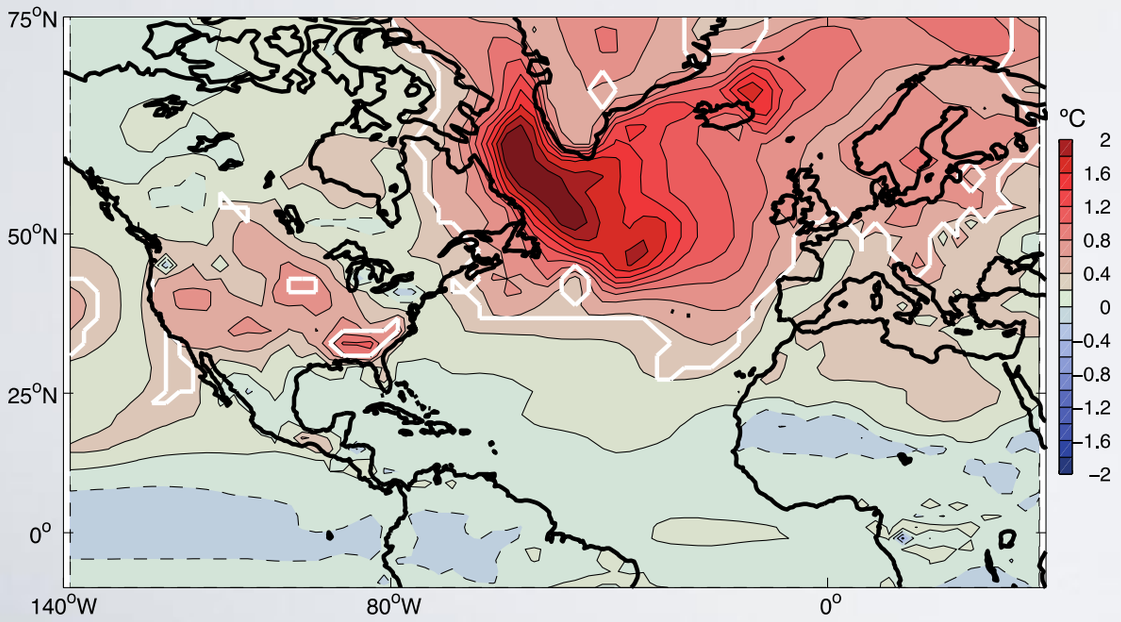


Initialization Enables Prediction on Shift in Sub-Polar Gyre



Initialization leads to skillful predictions of sub-polar gyre (SPG) shift in 1994-1995. Uninitialized predictions fail.

Successful predictions due to the initialization and prediction of enhanced AMOC.



JJA surface air temperature associated with the SPG warming (lead 6-10 years)

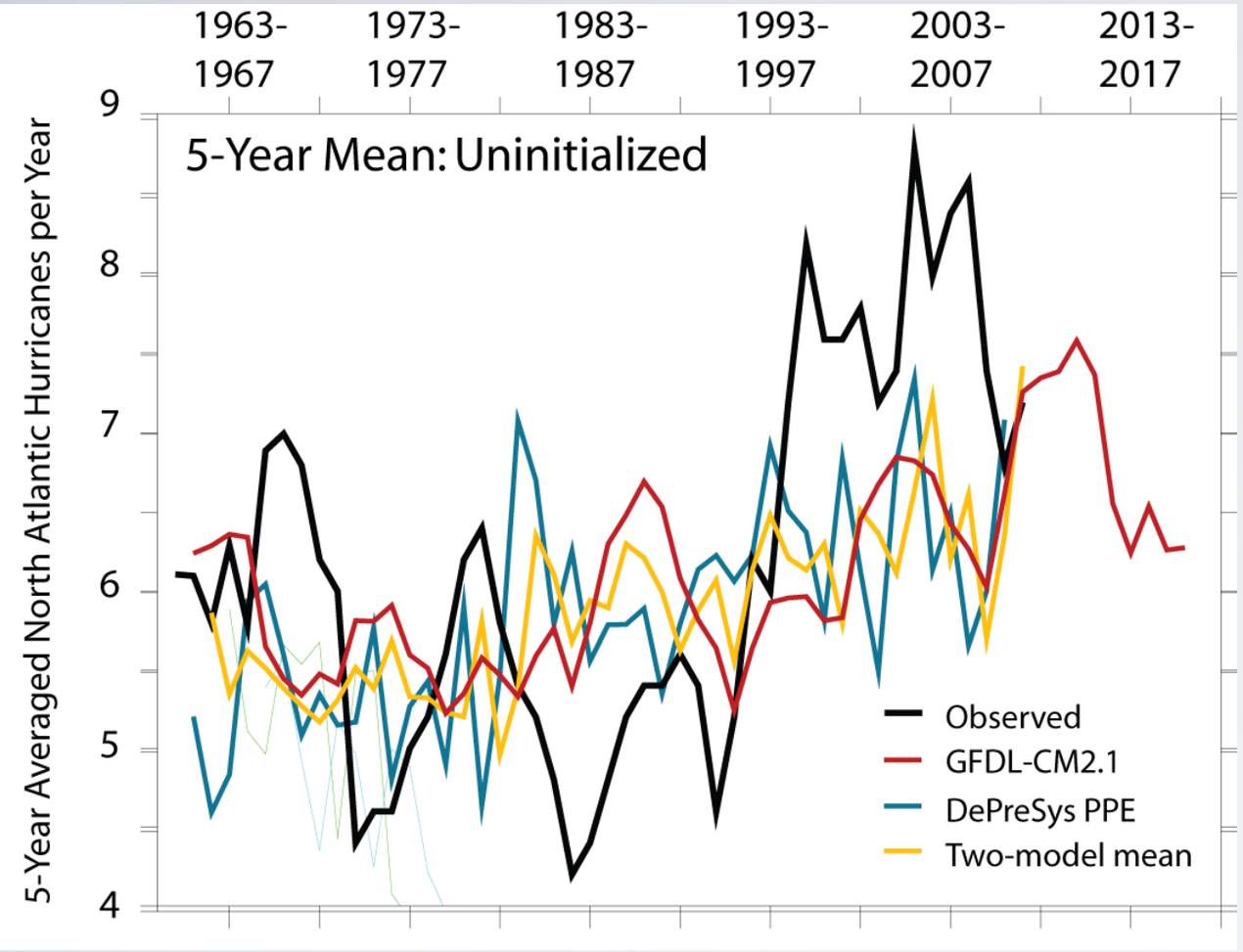
Msadek et al. (2013)

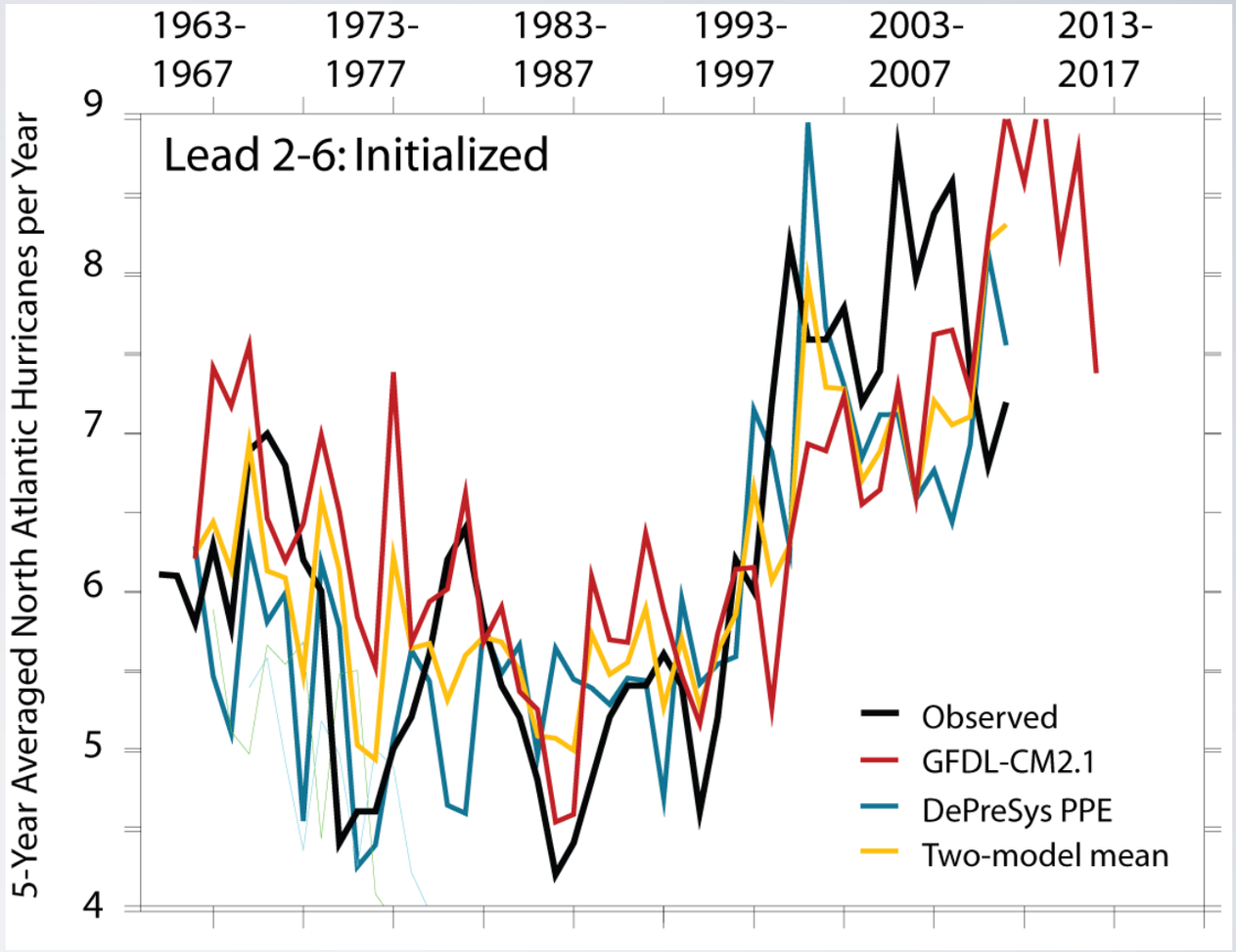
5-year hurricane predictions

Hybrid system: statistical hurricanes, dynamical decadal climate forecasts

FORCED

FORCED & INTIALIZED



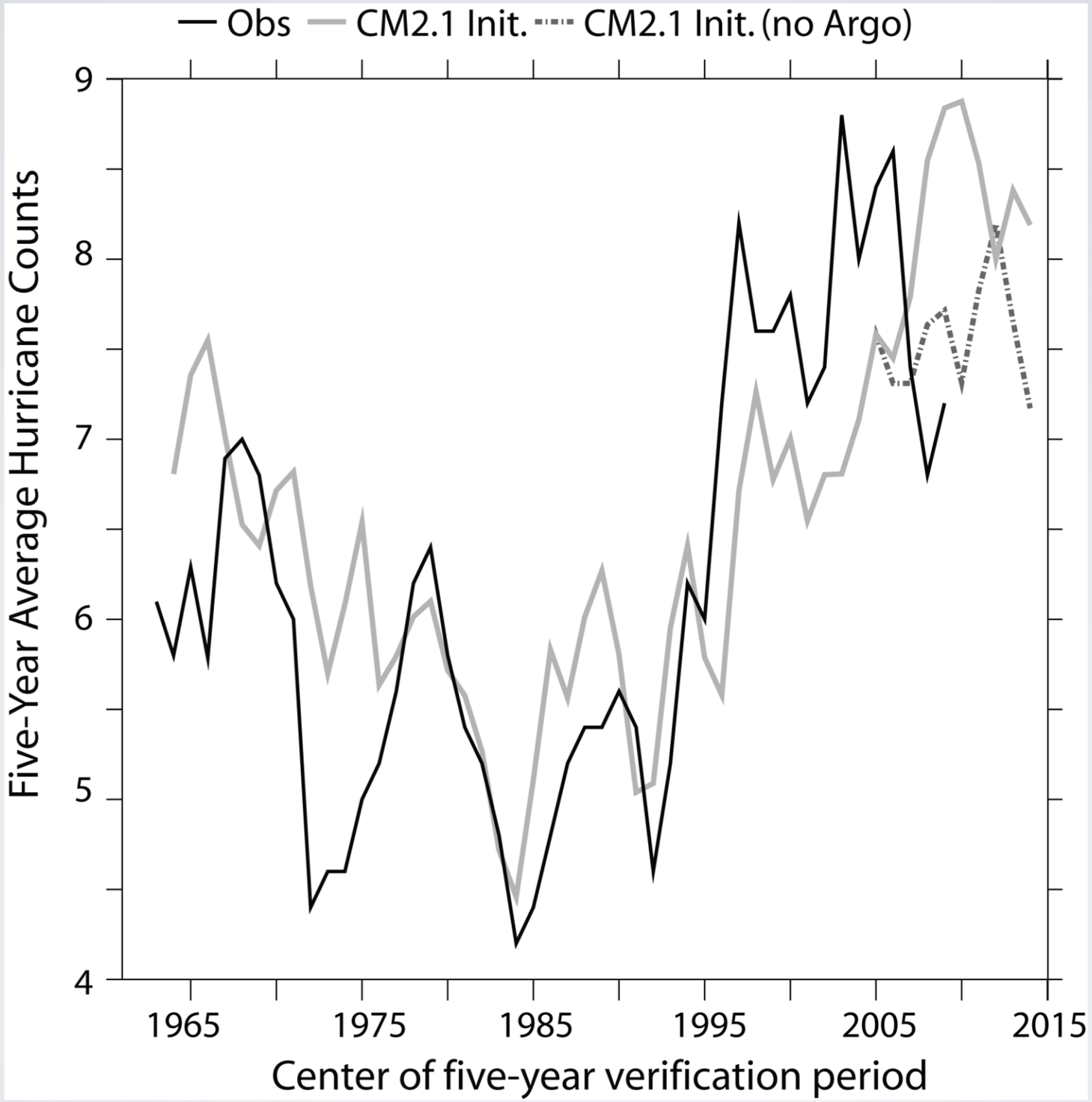


- Retrospective predictions encouraging.
- However, very small sample size limits confidence
- Skill arises more from recognizing 1994-1995 shift than actually predicting it.

EXPERIMENTAL: NOT OFFICIAL FORECAST

Vecchi et al. (2013.a, J. Clim.)

Removing observational inhomogeneity removes post-2004 upswing: **need stable, sustained observations**



Vecchi et al. (2013.a, J. Climate)

Impact of Resolution on Simulation and Prediction

Hypothesis: Enhanced resolution will lead to improved simulation and prediction of climate.

Goal: Build a seasonal to decadal forecasting system to:
Yield improved forecasts of large-scale climate
Enable forecasts of regional climate and extremes

High Resolution Coupled Model Development

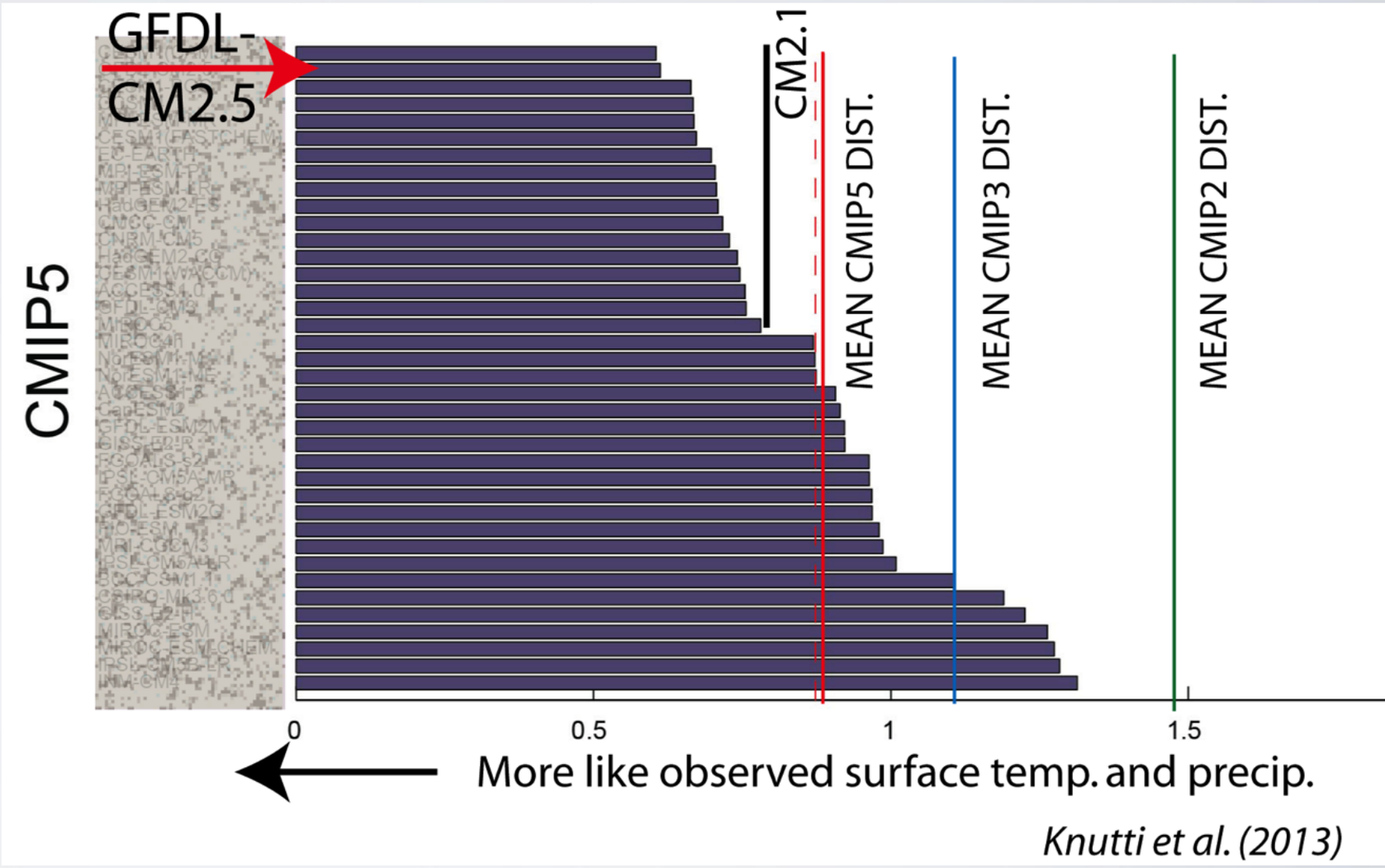
Scientific Goals:

- **Developing improved models (higher resolution, improved physics and numerics, reduced bias) for studies of variability and predictability on intra-seasonal to decadal time scales**
- **Explore impact of atmosphere and ocean on climate variability and change using a high resolution coupled model**
- **New global coupled models: CM2.4, CM2.5, CM2.6, …**

	Ocean	Atmos
CM2.1	100 Km	250 Km
CM2.3	100 Km	100 Km
CM2.4	10-25 Km	100 Km
CM2.5	10-25 Km	50 Km
CM2.6	4-10 Km	50 Km

GFDL-CM2.5 produces one of best global surface climate simulations of present model generation

Faster computer (GAEA) allows improved resolution that translates into significantly reduced biases in CM2.5 relative to CM2.1



Knutti et al. (2013)

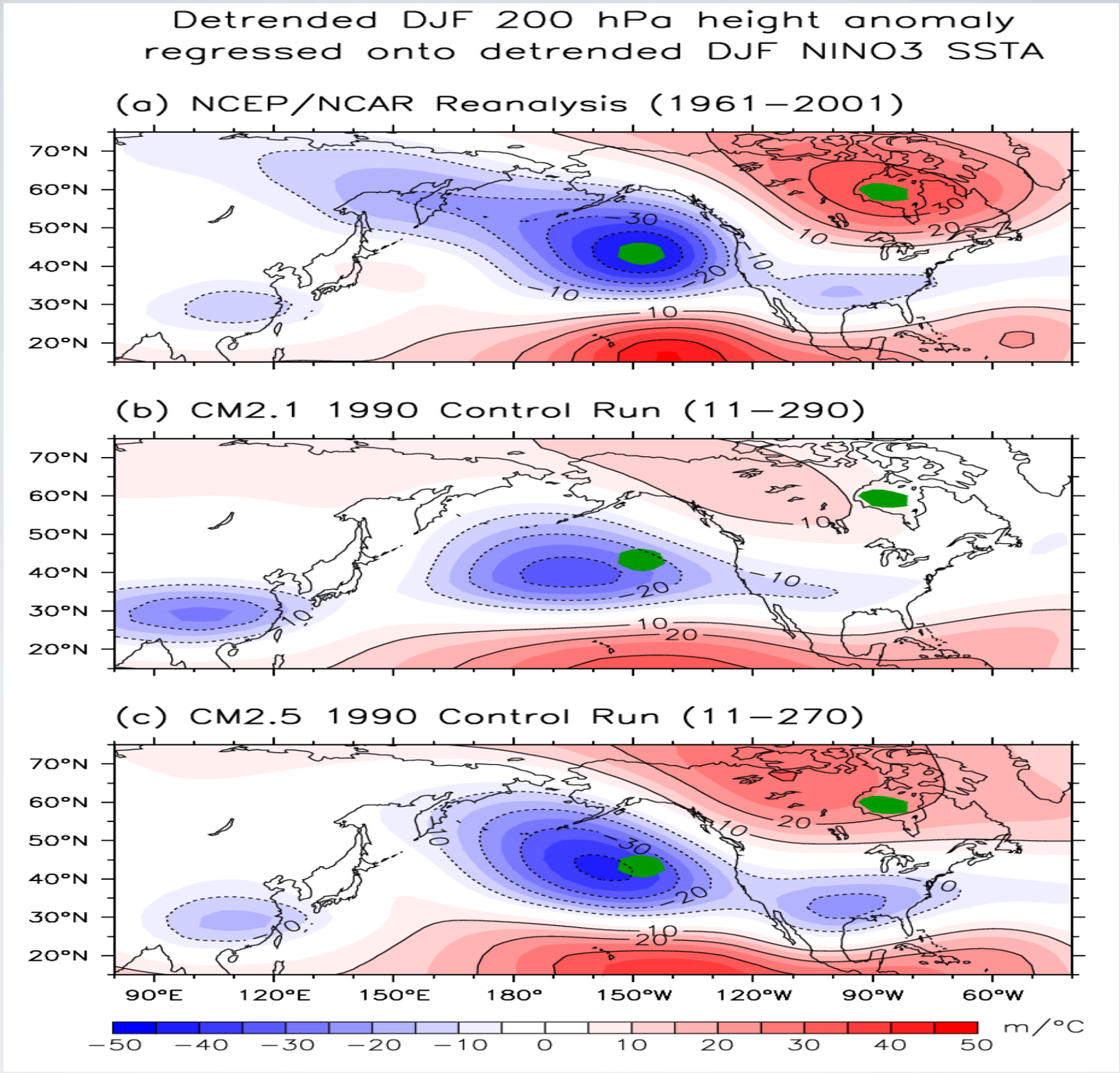
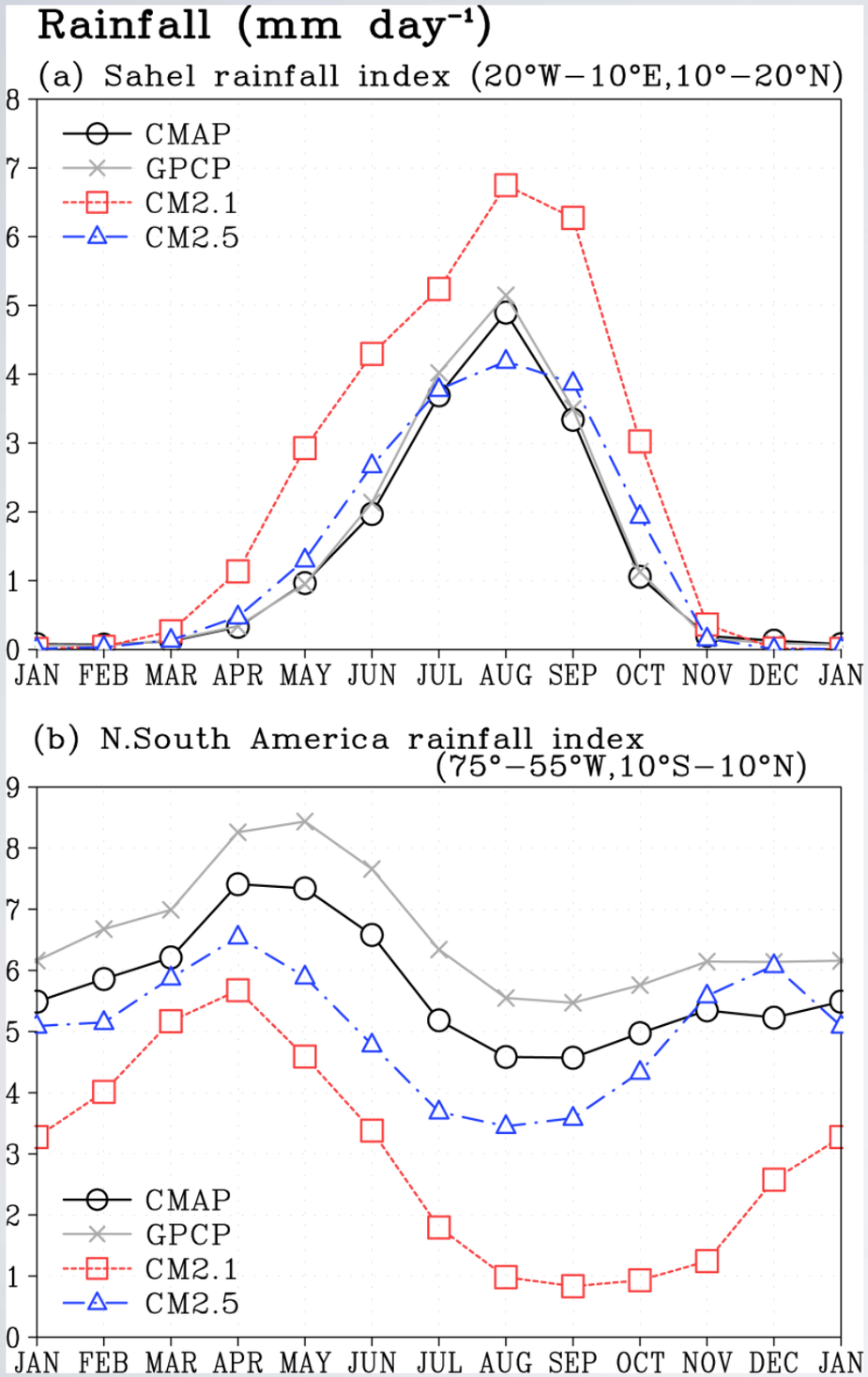


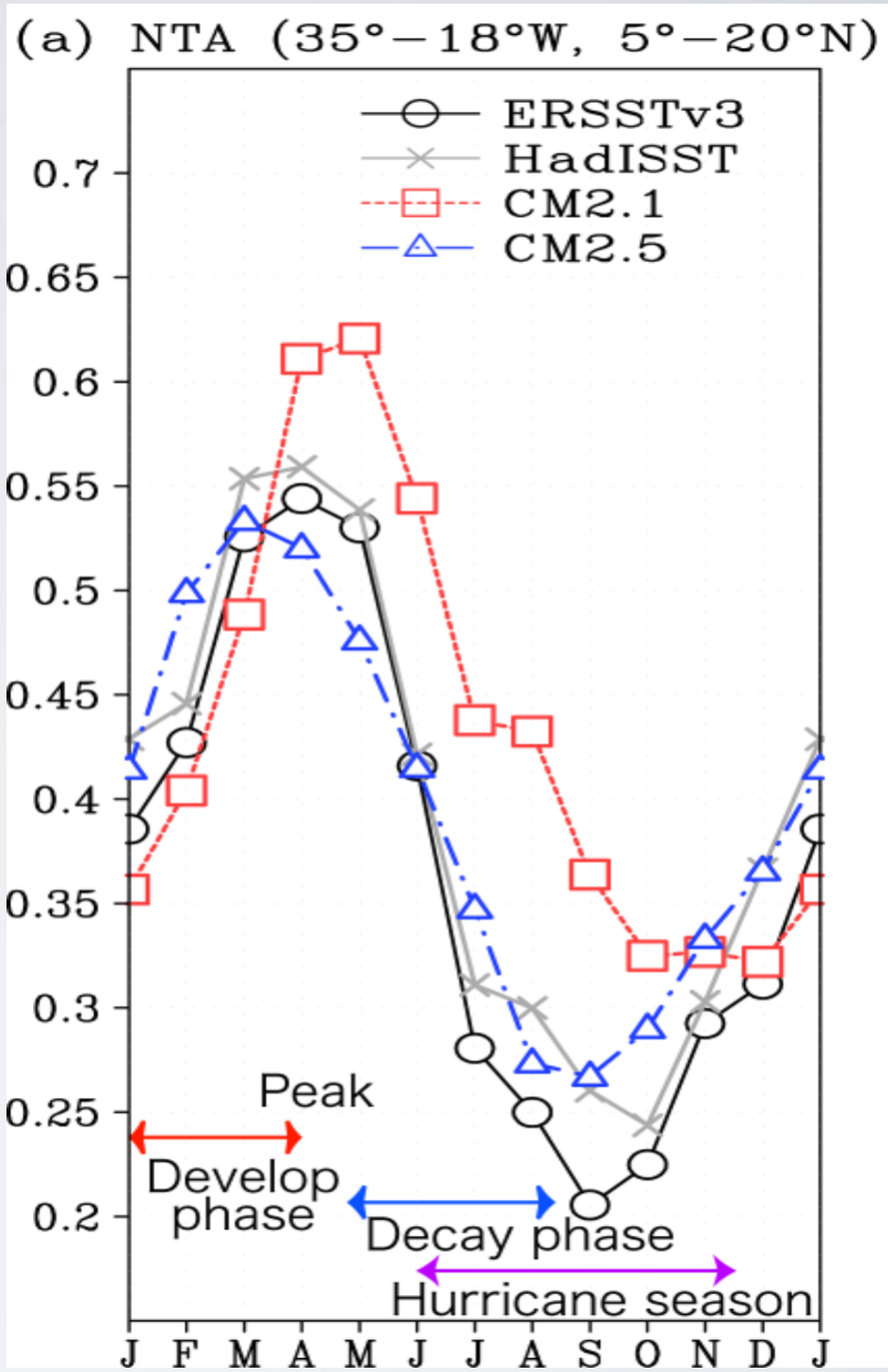
Figure 17 DJF 200-hPa geopotential height anomalies regressed onto DJF NINO3 SSTAs, computed using (a) the NCEP/NCAR Reanalysis (Kistler et al. 2001) for 1961-2001; (b) the CM2.1 1990 control run for years 11-290; (c) the CM2.5 1990 control run for years 11-0270. The zero contour is omitted. Green shading in all panels indicates the positions of the observed extrema over the North Pacific and Canada. Prior to computing the seasonal anomalies and regressions, all time series were detrended by removing a 20-yr running mean.

N. Tropical Atlantic Climate Improves from better Atlantic ITCZ simulation

Climatological Rainfall



Interannual SST Standard Dev.



Doi et al. (2012)

Modified Hypothesis:

Enhanced atmosphere & land resolution will lead to improved simulation and prediction of climate.

GFDL FLOR: Experimental high-resolution coupled seasonal to decadal prediction system

Goal: Build a seasonal to decadal forecasting system to:

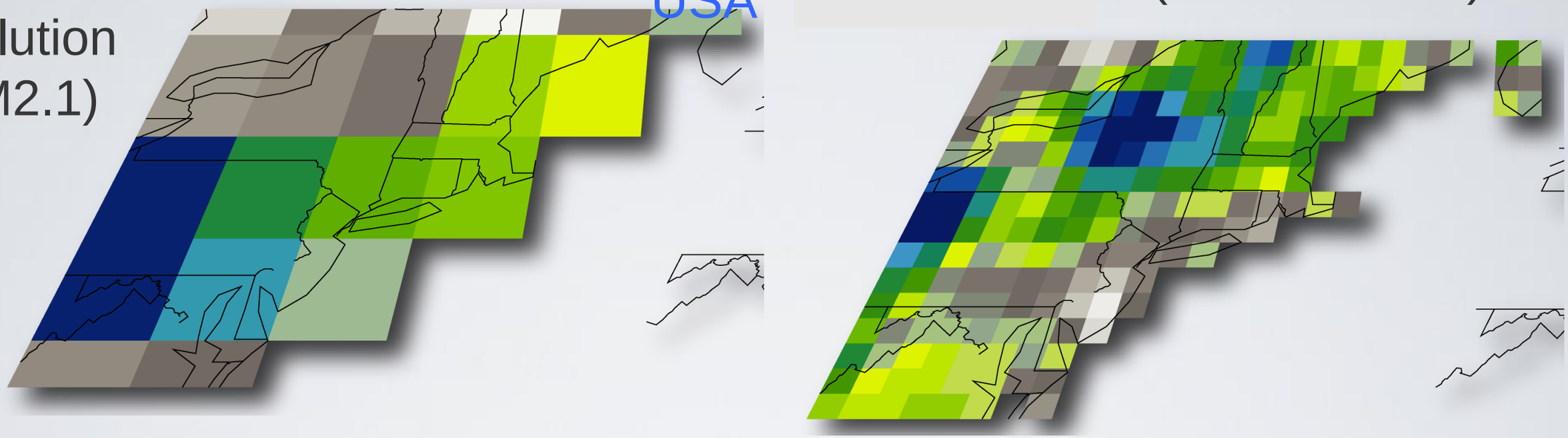
Yield improved forecasts of large-scale climate

Enable forecasts of regional climate and extremes

Precipitation in Northeast USA

Medium resolution (CM2.1)

High resolution (CM2.5-FLOR)



Delworth et al. (2012), Vecchi et al. (2013, in prep.)

Modified version of CM2.5 (Delworth et al. 2012):

- 50km cubed-sphere atmosphere
- 1° ocean/sea ice (low res enables prediction work)

~15-18 years per day. Multi-century integrations. 4500+ model-years of experimental seasonal predictions completed and being analyzed.

Hypothesis: Enhanced atmos./land resolution improves climate

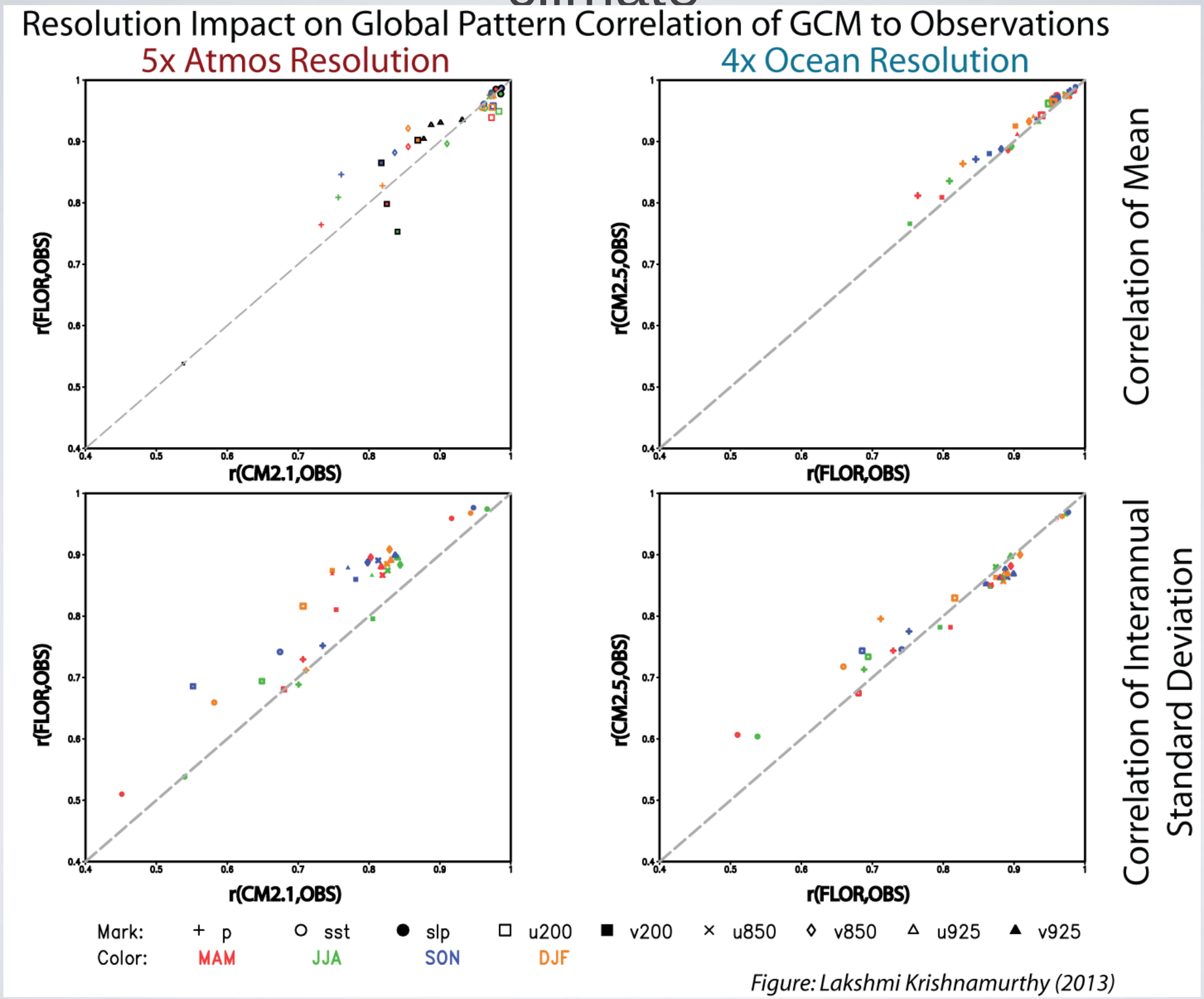


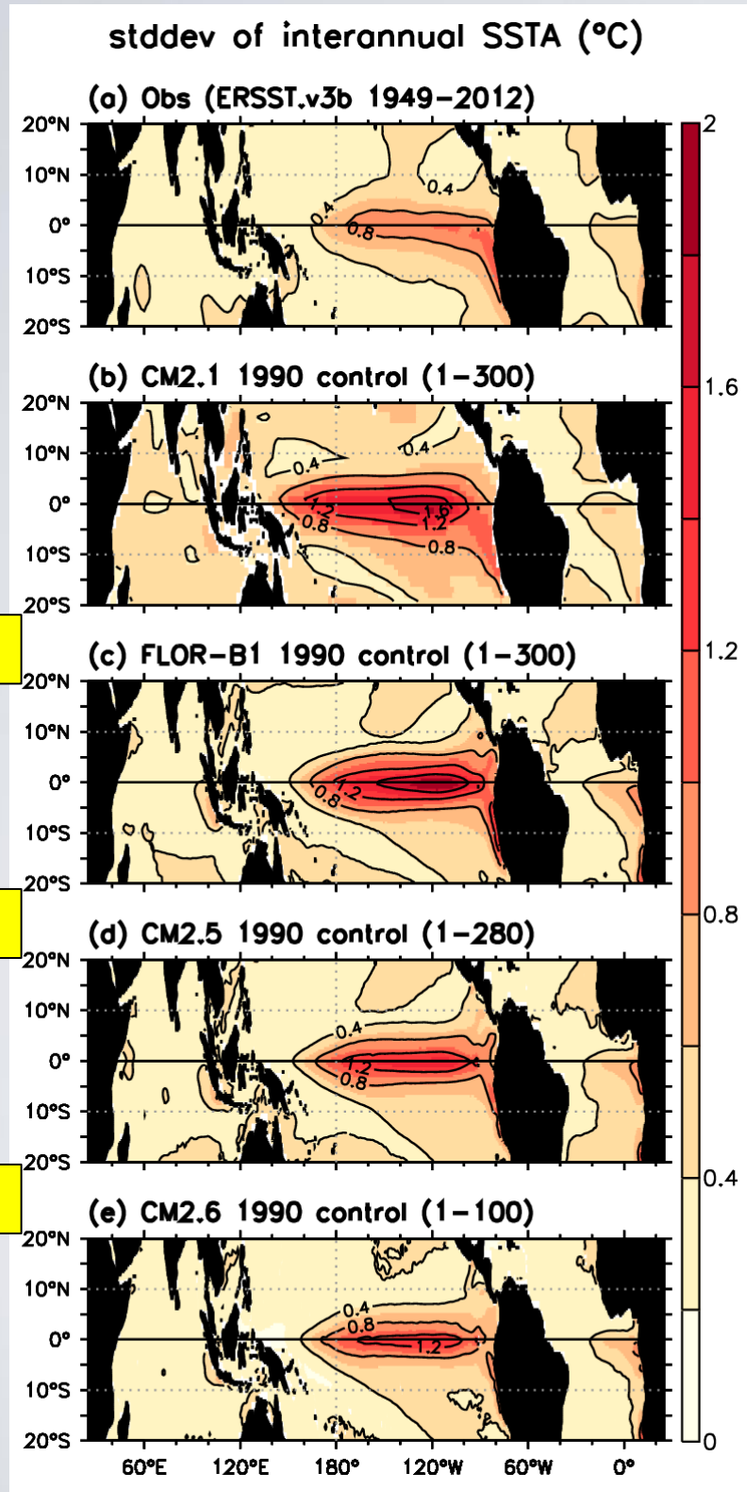
Figure: Lakshmi Krishnamurthy (2013)

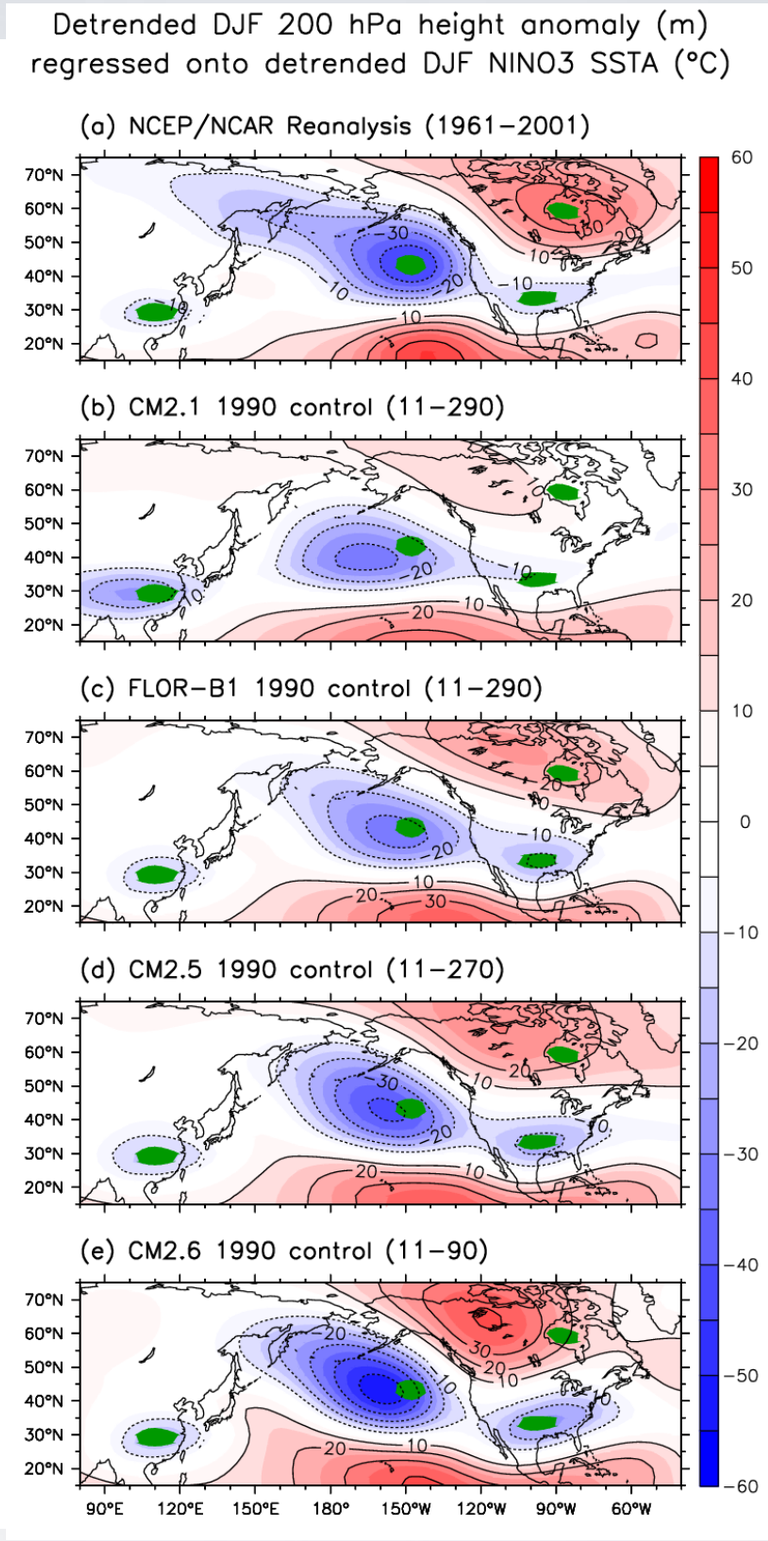
ENSO simulation changes with increasing resolution

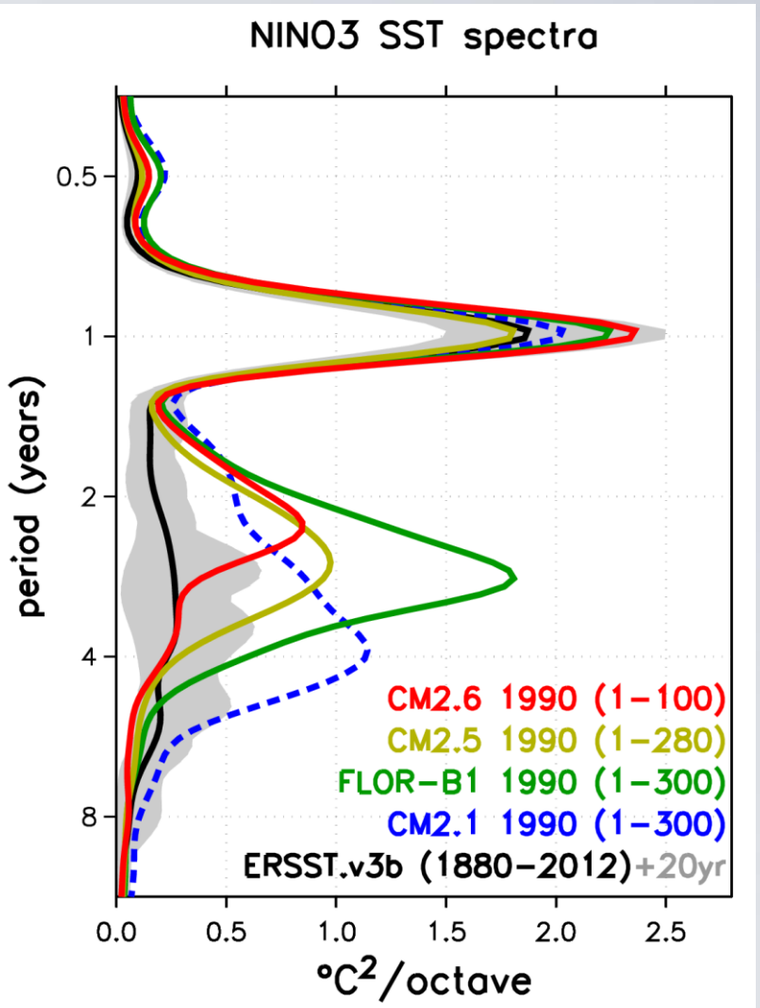
5x atm

4x ocn

2.5x ocn







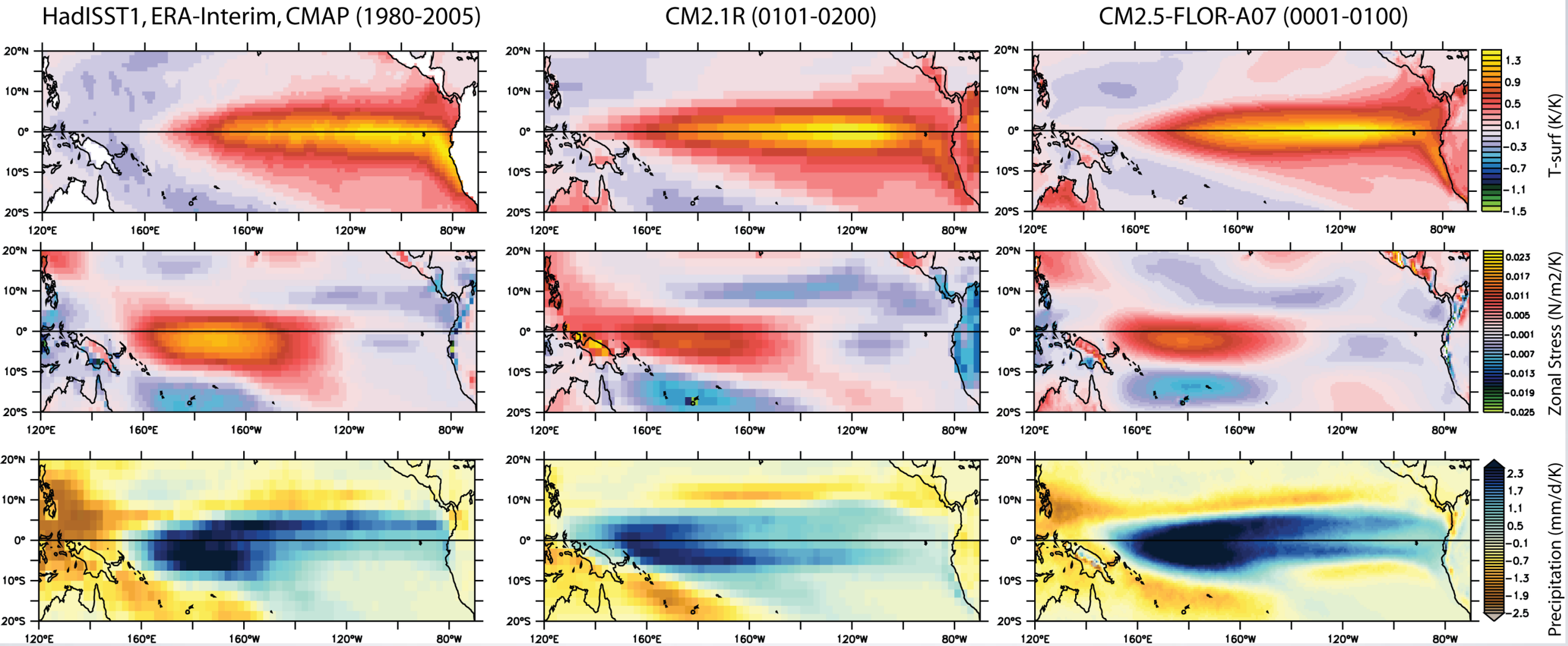
As resolution increases:

- SSTAs weaken & shift eastward
- PNA response strengthens
- ENSO period shortens

See also:
Delworth et al. (JC 2012)

Structure of ENSO anomalies improves in FLOR (captures much of CM2.5's improvement)

Regressions onto NIÑO3 SSTA



OBS

Med. Resolution

CM2.1

New high-res model

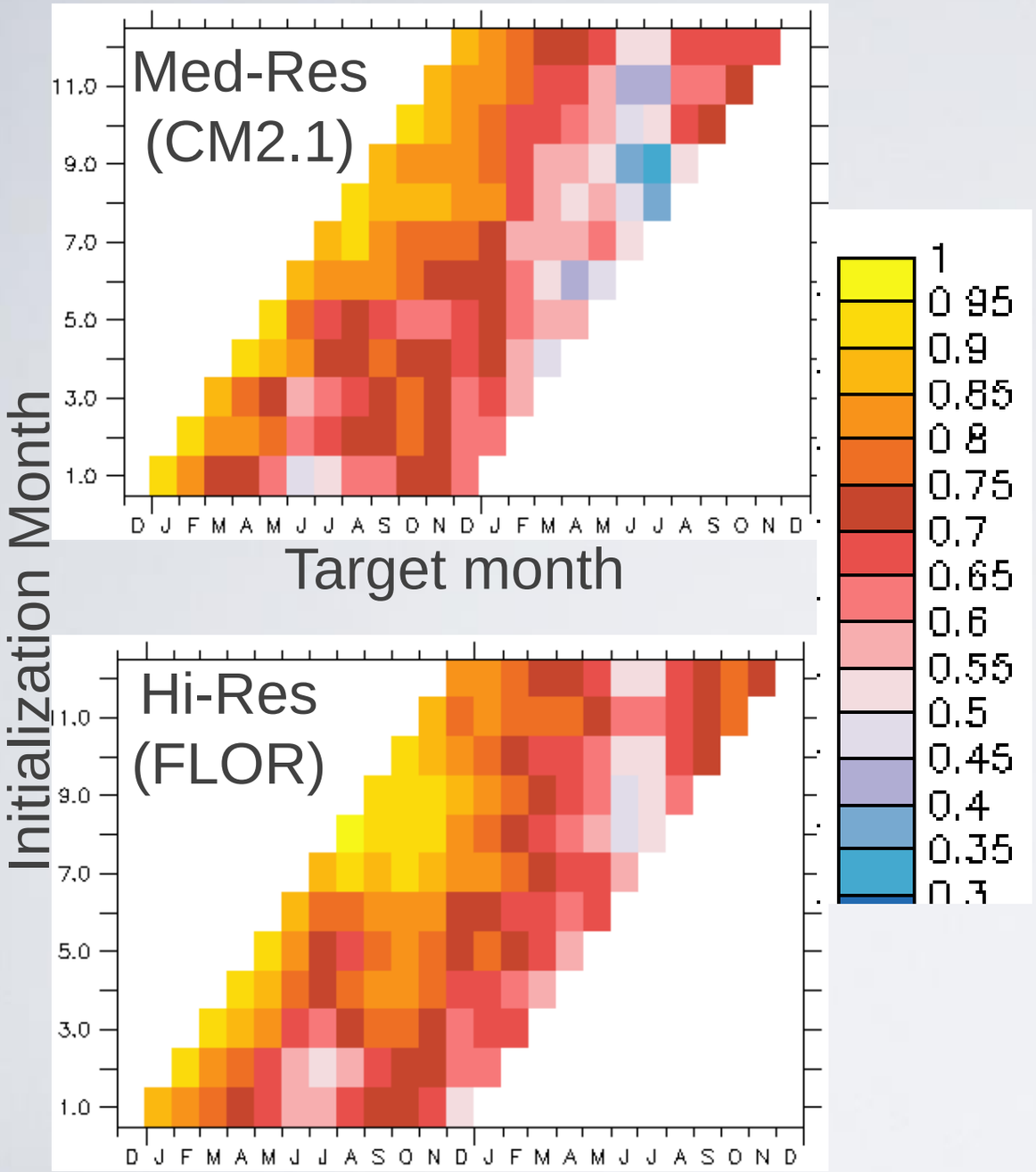
FLOR

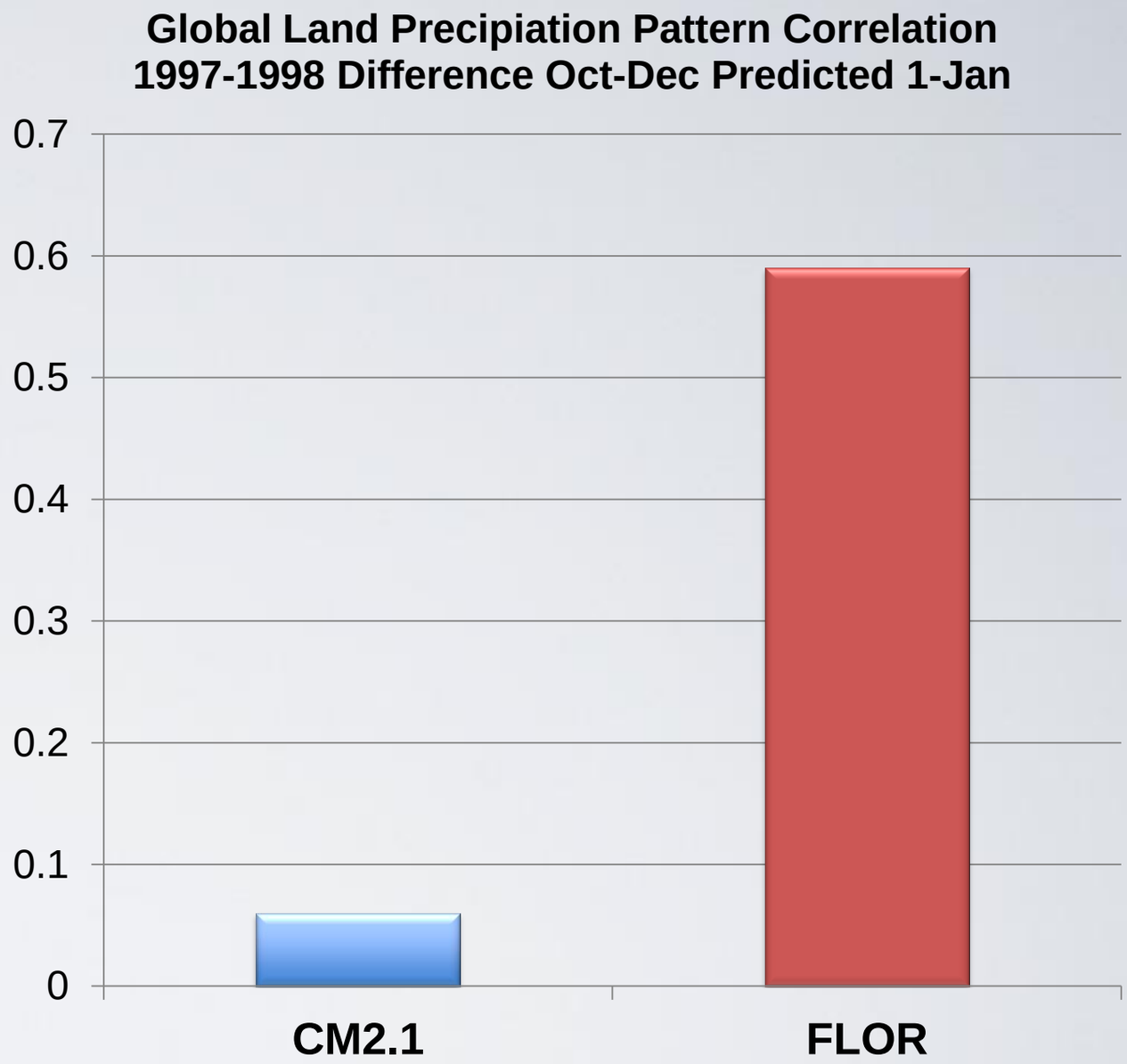
Phased approach to explore FLOR forecasts

Phase 1	**Use CM2.1's ocean-ice ICs, run 1980-present forecasts. Single Atm.**	**SI forecasts completed mid-2013, initial evaluation and decadal experiments underway**
Phase 2	**Build coupled assimilation on high-res system, run 199X-present forecasts. Single atm.**	**Need to finalize model, assimilation strategy, etc. Done late 2013 to early 2014. (~double cp need to Phase 1 so more months or more cp/month)**
Phase 3	**A: Coupled assimilation. Ultra-high res atm.**	**In development.**
	B: Coupled assimilation. (Multi-AM?) interactive ensemble.	

Preliminary FLOR forecast results: Improved skill relative CM2.1
(both using CM2.1 I.C.s – not our "best shot")

Correlation 1982-2012 NIÑO3.4

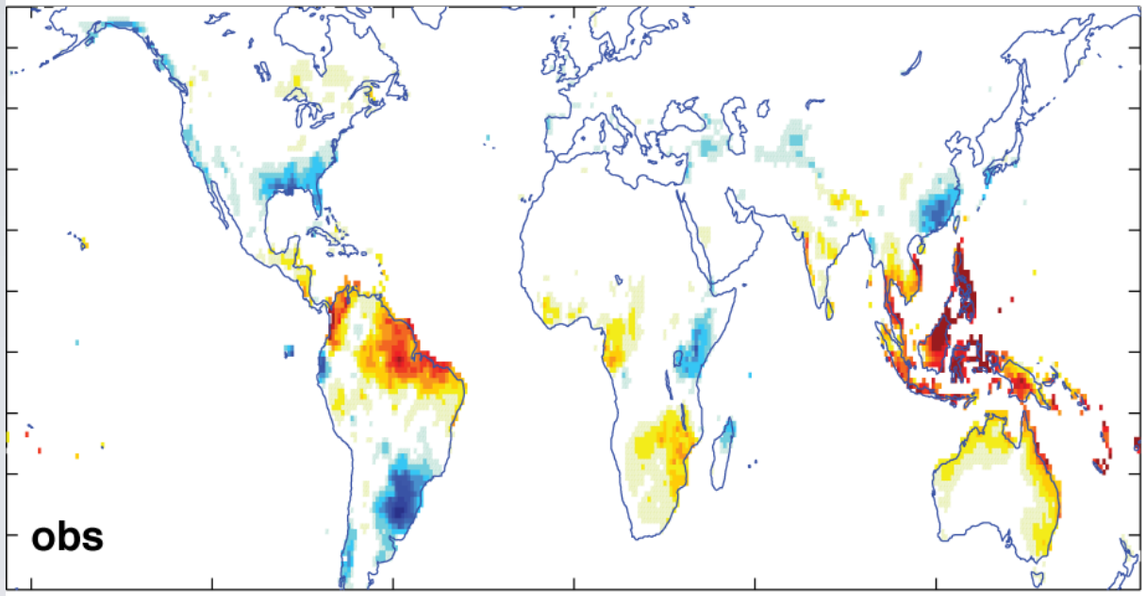


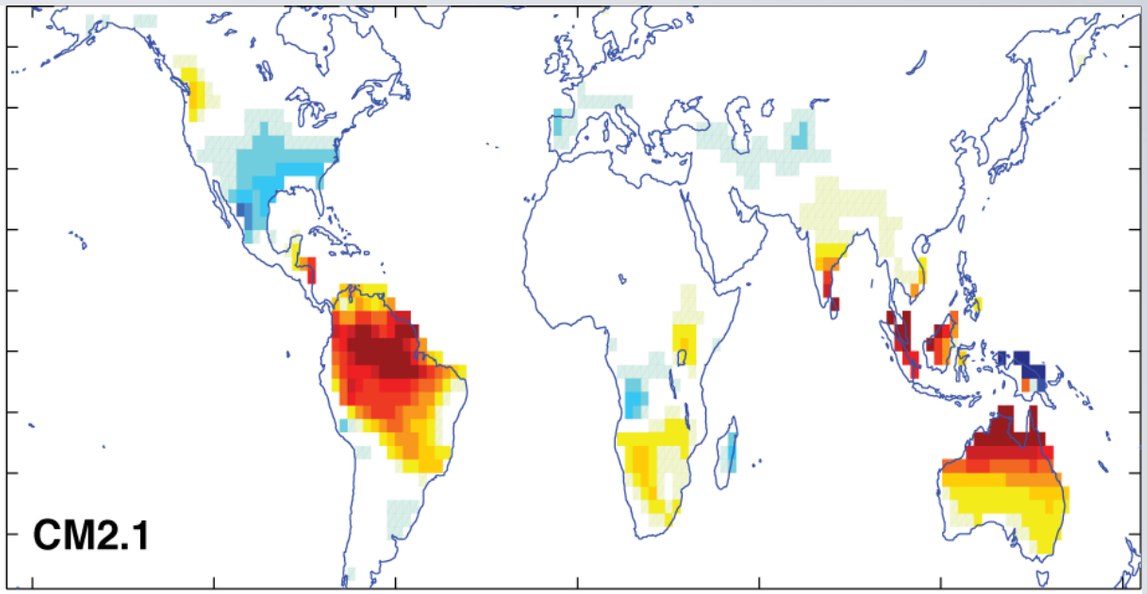


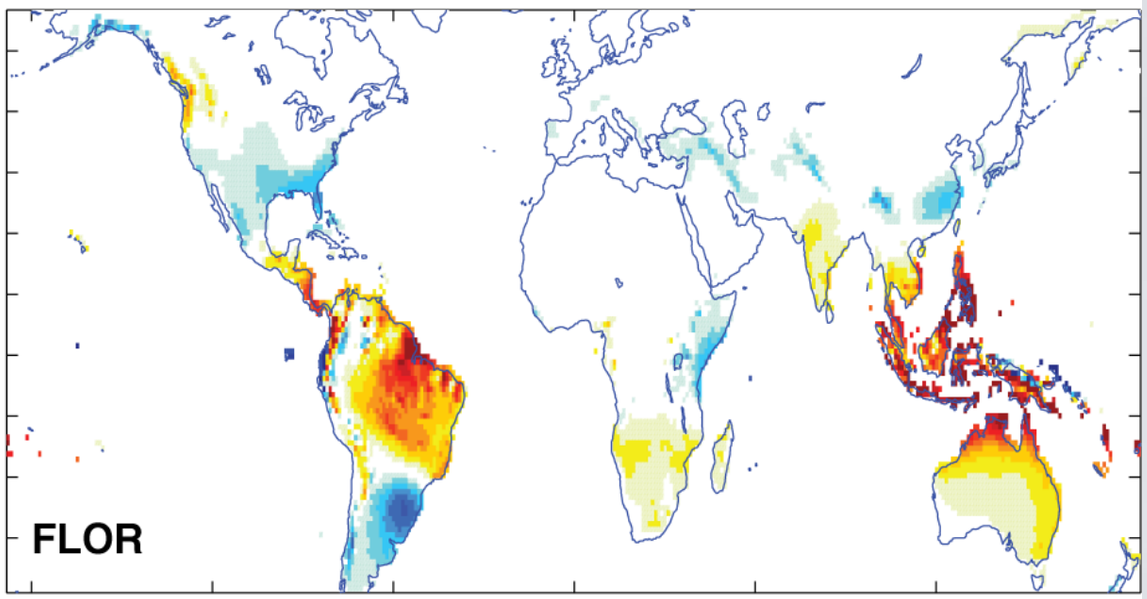
Increase in skill for global and regional surface temperature and precipitation over land (Jia et al. 2013, in prep.)

“Most predictable” land precipitation mode better represented in FLOR than CM2.1 predictions

Leading land precip. APT mode







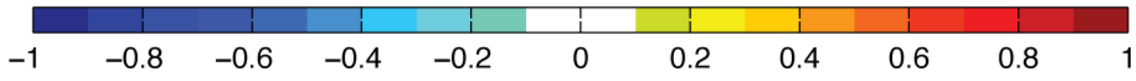


Figure: Liwei Jia - *Jia et al. (2013, in prep.)*

Retrospective (1982-2012) initialized prediction skill of “most predictable” precip. mode improved in FLOR

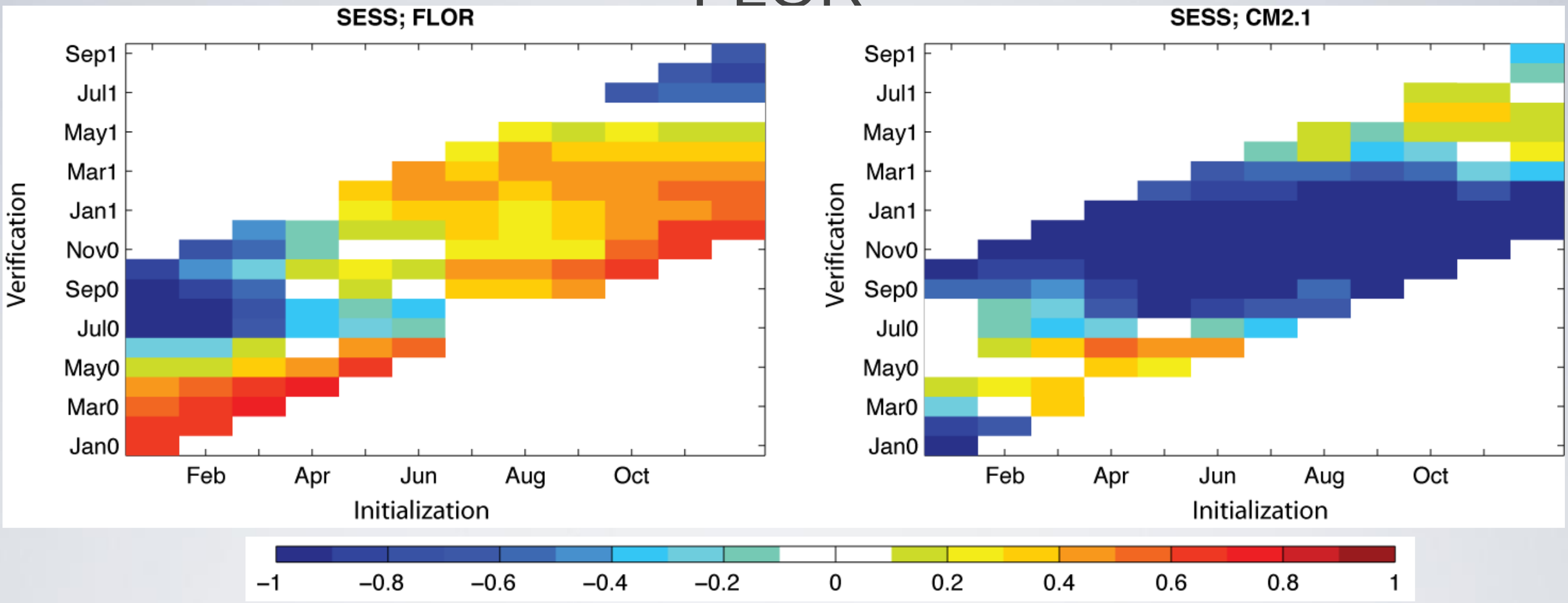
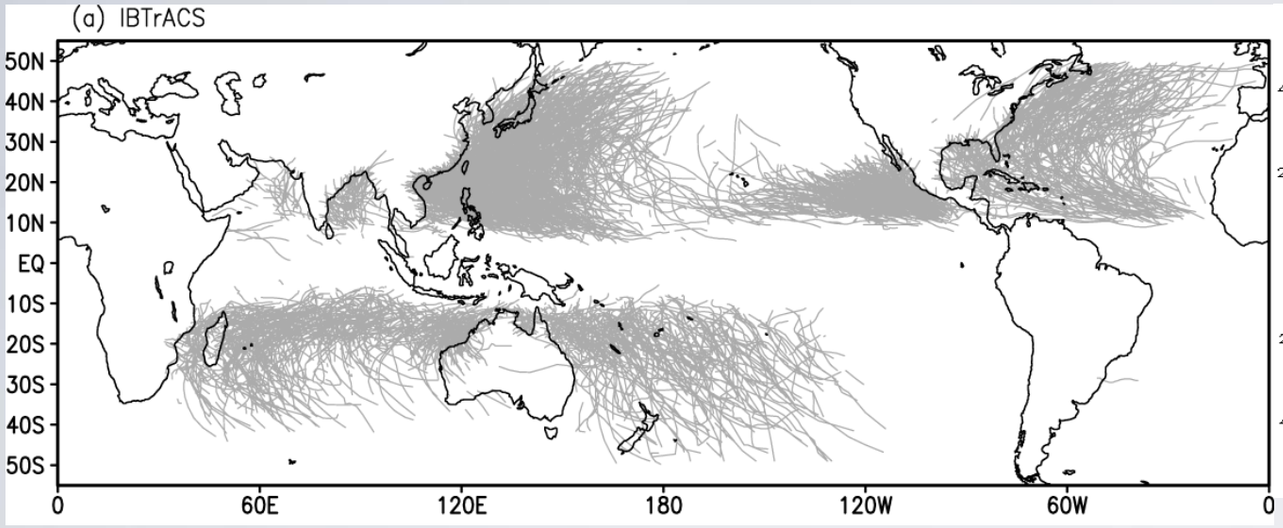


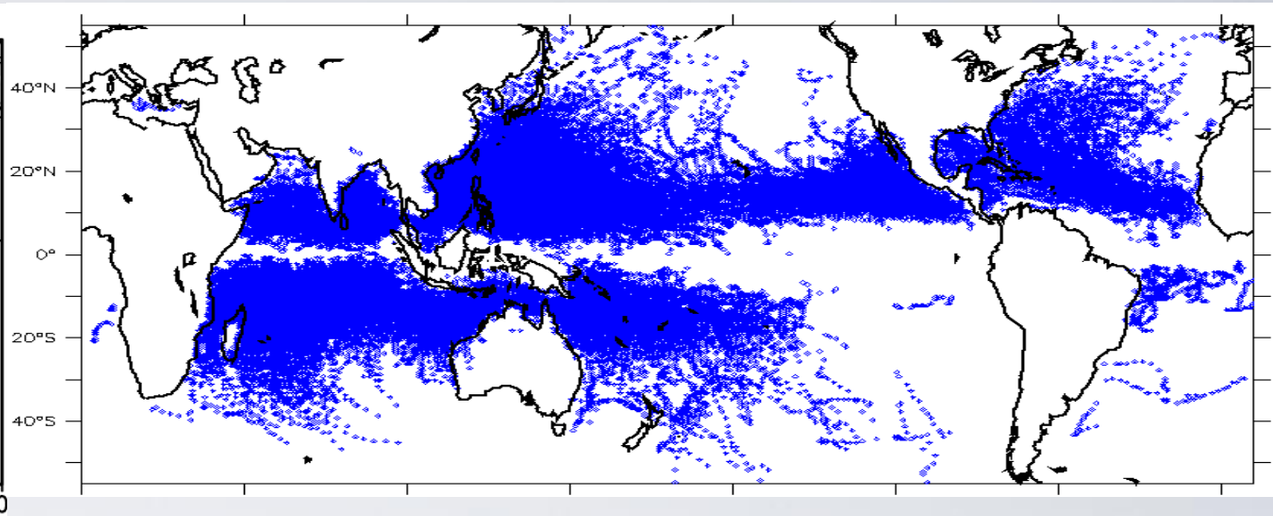
Figure: Liwei Jia - *Jia et al. (2013, in prep.)*

Towards seamless seasonal-to-centennial TC changes in high-resolution global coupled models

Observed Tracks (30y)

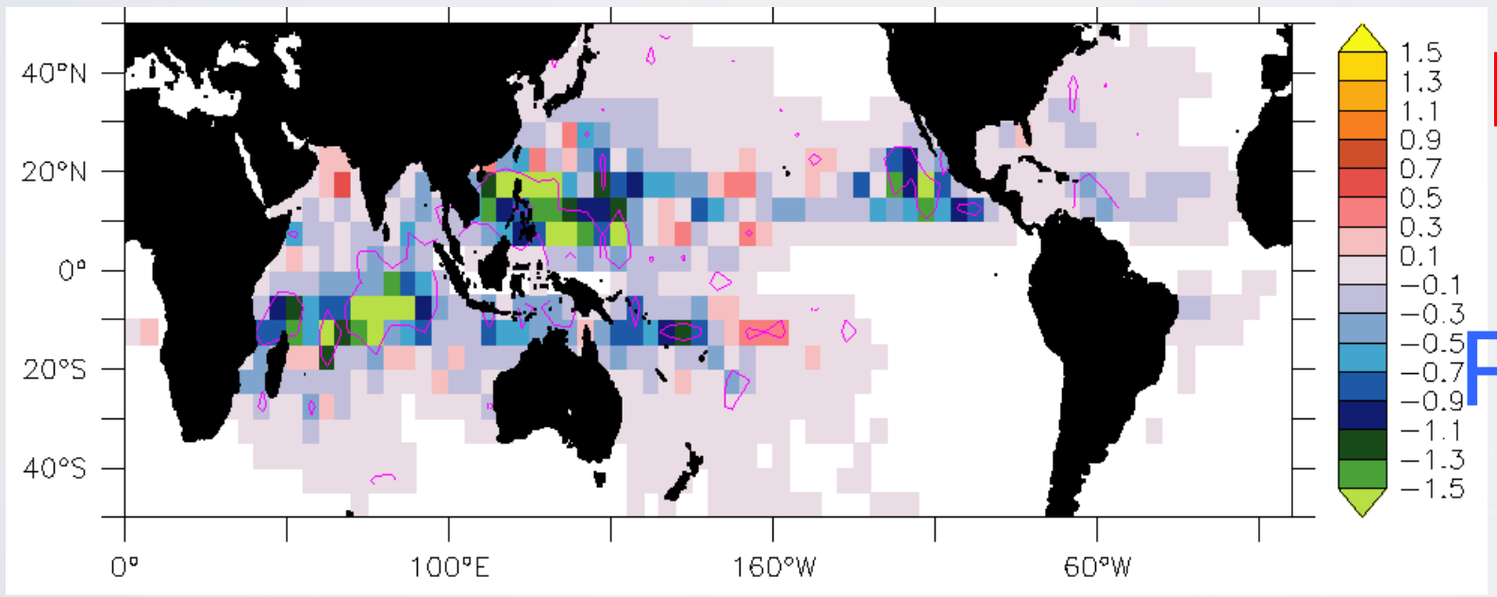


Coupled Model Tracks (360y actual seasonal forecast



Vecchi et al. (2013, in prep.)

CM2.5 Tropical storm density response to CO_2 doubling

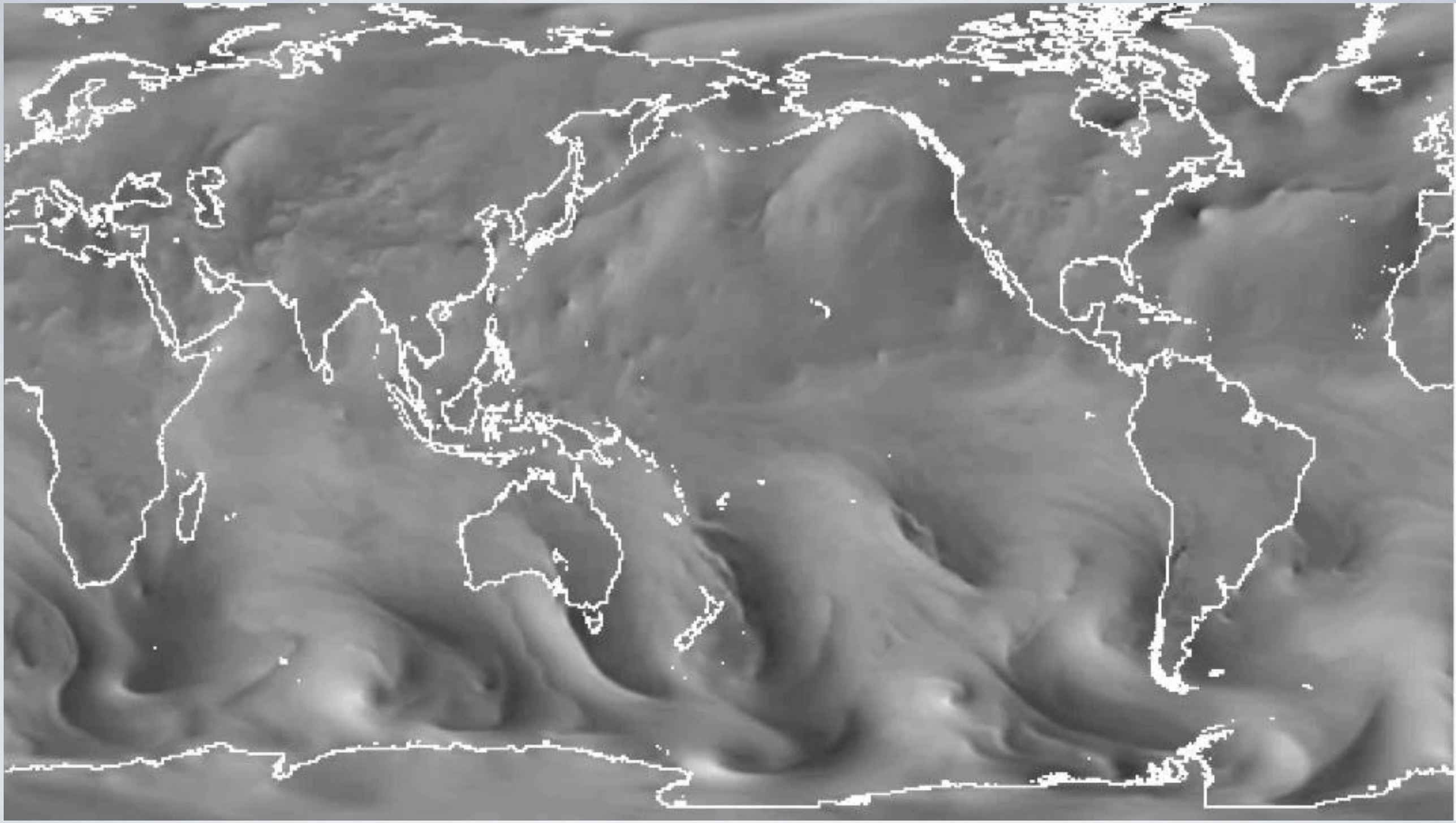


More storms

Fewer storms

(Kim et al. 2013)

100 days of single ensemble of 1-Aug-2005 initialized CM2.5-FLOR 10-m v



4xdaily 1-Aug through 8-Nov 2005

Summary

Successful initialized prediction requires strong efforts in:

- Coupled model development
- Assimilation devepment
- Sustained observing systems
- Analysis methodology

Initialized predictions yielding exciting results on seasonal to decadal timescales

- Dealing with observing system inhomogeneity remains a challenge
- Model bias impacts skill through drift/shock, accentuating impacts of obs. system changes and complicating assimilation analysis

Initialized predictions test models in ways “free running” simulations do not: valuable

High-resolution seasonal to decadal predictions

- CM2.5-FLOR: towards seamless seasonal to centennial prediction/projection of regional and extremes (50km/CM2.5 atmosphere/land - Delworth et al. 2012; 1°/CM2.1 ocean/ice – Delworth et al. 2006)
- 4500+ years of retrospective forecasts: encouraging results on precip, continental temp,

Potential FLOR versions: how the sausage was made